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Structural Drawing

251 ILLUSTRATIONS

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MATHEMATICS FOR STRUCTURAL DRAWING
ELEMENTS OF STRUCTURAL DRAWING
ELEMENTS OF CONCRETE DRAWING
ELEMENTS OF TIMBER DRAWING

Published by
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.
1928

Printed in U. S. A.

PRESS OF
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.
447B

93162

PREFACE

The volumes of the International Library of Technology are made up of Instruction Papers, or Sections, comprising the various courses of instruction for students of the International Correspondence Schools. The original manuscripts are prepared by persons thoroughly qualified both technically and by experience to write with authority, and in many cases they are regularly employed elsewhere in practical work as experts. The manuscripts are then carefully edited to make them suitable for correspondence instruction. The Instruction Papers are written clearly and in the simplest language possible, so as to make them readily understood by all students. Necessary technical expressions are clearly explained when introduced.

The great majority of our students wish to prepare themselves for advancement in their vocations or to qualify for more congenial occupations. Usually they are employed and able to devote only a few hours a day to study. Therefore every effort must be made to give them practical and accurate information in clear and concise form and to make this information include all of the essentials but none of the non-essentials. To make the text clear, illustrations are used freely. These illustrations are especially made by our own Illustrating Department in order to adapt them fully to the requirements of the text.

In the table of contents that immediately follows are given the titles of the Sections included in this volume, and under each title are listed the main topics discussed.

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CONTENTS

NOTE.—This volume is made up of a number of separate Sections, the page numbers of which usually begin with 1. To enable the reader to distinguish between the different Sections, each one is designated by a number preceded by a Section mark (§), which appears at the top of each page, opposite the page number. In this list of contents, the Section number is given following the title of the Section, and under each title appears a full synopsis of the subjects treated. The table of contents will enable the reader to find readily any topic covered.

ELEMENTS OF STRUCTURAL DRAWING

(*Continued*)

ELEMENTS OF STRUCTURAL DRAWING

(*Continued*)

ELEMENTS OF STRUCTURAL DRAWING

(*Continued*)

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ELEMENTS OF CONCRETE DRAWING

(*Continued*)

ELEMENTS OF CONCRETE DRAWING

(*Continued*)

ELEMENTS OF TIMBER DRAWING, § 17

ELEMENTS OF TIMBER DRAWING

(*Continued*)

MATHEMATICS FOR STRUCTURAL DRAWING

SMOLEY'S TABLES

INTRODUCTION

1. Structural Computations.—Two important features distinguish the computations in structural work from other engineering calculations. In the first place, lengths in structural work are usually expressed in feet, inches, and fractions of an inch instead of in feet and decimals of a foot. Secondly, the directions of lines are given by *bevels* instead of angles in degrees, minutes, and seconds.

2. Bevels.—Let it be required to draw a line AC, Fig. 1, so as to make an angle BAC, say 42° 11′, with AB. The angle may be plotted by means of its natural tangent, which is .9062, as follows: Lay off AD equal to 1 foot, to some convenient scale, draw DM perpendicular to AB, and, along DM, make DE equal to .9062 foot, to the same scale.

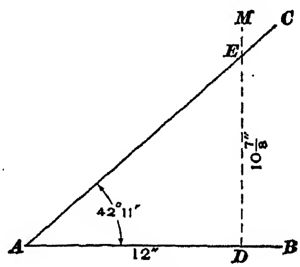

FIG. 1

Then, by definition, $\tan CAB = \frac{ED}{AD} = \frac{.9062}{1} = .9062$. Hence, the line AC through E is the required line. Instead of the decimal of a foot represented by the natural tangent, as .9062 foot, it is customary in structural work to take its

equivalent in inches and a fraction of an inch; in the given case, it equals $.9062 \times 12 = 10.8744$ inches $= 10\frac{7}{8}$ inches. Thus, to plot the angle BAC, Fig. 1, AD would be made equal to 12 inches and DE equal to $10\frac{7}{8}$ inches. The distance DE, expressed in inches and a fraction of an inch, is called the *bevel* of AC with respect to AB; and the line AB, to which the bevel is referred, is called the *reference line*.

Theoretically, a bevel is a natural tangent, expressed as a ratio in which the denominator is always 12 inches and the numerator is a number of inches and a fraction of an inch: thus, the bevel of the line AC, Fig. 1, with reference to AB, is $\frac{10\frac{7}{8}}{12}$. However, in practice, when the bevel is specified, the numerator of the fraction alone is mentioned, the denominator being implied as 12 inches; for example, the bevel of AC is referred to as $10\frac{7}{8}$ inches.

3. Smoley's Tables.—If the common methods are used in structural calculations, the work is very laborious. It is then necessary to change frequently from inches and fractions to decimals of a foot, and vice versa. Furthermore, if only tables of logarithms of numbers and of trigonometric functions are used in solving problems involving bevel calculations, values must often be found by indirect methods and by interpolation.

Structural computations are simplified and made easier by the use of *Smoley's Tables*. This handbook is in two parts. Part 1 consists of Parallel Tables of Logarithms and Squares, Graphic Solution of a Right Triangle, Tables of Angles and Natural and Logarithmic Functions Corresponding to Bevels. Multiplication Table for Rivet Spacing, and Multiplication Table for Spacing of Lattice Bars. Part 2 contains Tables of Common Logarithms of Numbers, Tables of Logarithmic Functions, Tables of Natural Functions*, Tables of Circumferences, Areas, Squares, etc., Table of Lengths of Arcs for Radius 1, Tables of Areas and Circumferences of Circles for

*It will be noticed that in the Tables of Natural Functions only four decimal places are given. For structural calculations four decimal places are sufficient.

Diameters in Units and Fractions, and Tables of Decimal Equivalents. Thus, in addition to the standard tables on pages 1 to 170 of Part 2, which were treated in preceding Sections, there are many special tables, the description and application of which are given in the following articles.

TABLES OF DECIMAL EQUIVALENTS

4. Explanation.—The Tables of Decimal Equivalents, which are given in *Smoley's Tables* on pages 182 and 183 of Part 2, are used for reducing decimals of a foot to inches and fractions of an inch and, vice versa, for changing inches and fractions to decimals of a foot. Decimals of a foot may be changed to inches by multiplying by 12, and inches can be reduced to decimals of a foot by dividing by 12. Thus, .342 foot $=.342\times 12$ inches $=4.104$ inches $=4\frac{1}{8}$ inches, nearly; and $6\frac{5}{8}$ inches $=6.625$ inches $=\dfrac{6.625}{12}$ foot $=.552$ foot. These reductions are made more conveniently, however, by means of tables.

5. Use of Tables.—In the Tables of Decimal Equivalents the number of inches is given in the line immediately below the heading Decimals of a Foot, in intervals of 1 inch from 0 to 6 inches, inclusive, on page 182, and from 7 to 11 inches, inclusive, on page 183; the fractions of an inch are given in differences of $\frac{1}{32}$ from 0 to 1 in the columns headed Fractions of an Inch. To reduce a length given in inches and a fraction of an inch to its equivalent in decimals of a foot, the given number of inches is first located in the top line of figures, and the fraction in the nearest column headed Fractions of an Inch; the decimal equivalent is then found under the given number of inches, in the same line as the given fraction of an inch. Thus, the decimal equivalent of $4\frac{1}{2}$ inches is read under the heading 4″ in the same line as the fraction $\frac{1}{2}$ in the column headed Fractions of an Inch; it is .3750 foot.

The process of reducing a decimal of a foot to inches and a fraction of an inch is the reverse of that just explained. The

given decimal, or the nearest value in the tables, is first located; the number of inches in the required equivalent is then read at the head of the column containing that decimal, and the fraction of an inch, to the nearest $\frac{1}{32}$, is found opposite the decimal in the nearest column headed Fractions of an Inch.

EXAMPLE 1.—Reduce $7\frac{9}{16}$ inches to its equivalent decimal of a foot.

SOLUTION.—Under the heading 7″ and in the same line as $\frac{9}{16}$, is read .6302; therefore, $7\frac{9}{16}$ in. = .6302 ft. Ans.

EXAMPLE 2.—The length of a tube is measured as 2 feet $5\frac{13}{32}$ inches. What is the length in feet and decimals of a foot?

SOLUTION.—The number of feet, 2, is not affected. The decimal equivalent of $5\frac{13}{32}$ in., which is read under the heading 5″ in the same line as $\frac{13}{32}$, is .4505. Hence, 2 ft. $5\frac{13}{32}$ in. = 2.4505 ft. Ans.

EXAMPLE 3.—Reduce .3177 foot to inches and a fraction of an inch.

SOLUTION.—The value .3177 is found in the column headed 3″ opposite the fraction $\frac{13}{16}$. Therefore, .3177 ft. = $3\frac{13}{16}$ in. Ans.

EXAMPLE 4.—The length of a steel piece is computed as 22.635 ft. What is its length in feet, inches, and a fraction of an inch?

SOLUTION.—The number of feet is not changed. In the tables, the decimal nearest to .635 is .6354, which is found in the column headed 7″ on the same line with $\frac{5}{8}$. Hence, .635 ft. = $7\frac{5}{8}$ in. and 22.635 ft. = 22 ft. $7\frac{5}{8}$ in. Ans.

6. Decimals of an Inch.—The last column on page 183 of *Smoley's Tables*, headed Decimals of an Inch, gives the decimals of an inch that are equivalent to the fractions of an inch given in the preceding column headed Fractions of an Inch. Thus, $\frac{1}{32}$ inch = .03125 inch, $\frac{5}{8}$ inch = .62500 inch, $\frac{25}{32}$ inch = .78125 inch, etc.

To find the fraction, to the nearest $\frac{1}{32}$ inch, that corresponds to a decimal of an inch, locate the value nearest to the given number in the column headed Decimals of an Inch; the required fraction is opposite this decimal.

EXAMPLE 1.—Express $6\frac{5}{16}$ inches in inches and a decimal.

SOLUTION.—Only the fraction need be reduced. Thus, $\frac{5}{16}$ in. = .31250 in., and $6\frac{5}{16}$ in. = 6.3125 in. Ans.

EXAMPLE 2.—Express 9.7495 inches in inches and a fraction.

SOLUTION.—The value, in the column headed Decimals of an Inch, that is nearest to .7495 is .75000; and the fraction corresponding to .75000 is $\frac{3}{4}$. Hence, 9.7495 in. = $9\frac{3}{4}$ in. Ans.

EXAMPLES FOR PRACTICE

1. Reduce the following to feet and decimals of a foot:

(*a*) $\frac{3}{32}$ inch.	(*a*) .0078 ft.
(*b*) $9\frac{15}{16}$ inches.	(*b*) .8281 ft.
(*c*) $3\frac{21}{32}$ inches.	Ans. (*c*) .3047 ft.
(*d*) 3 feet $11\frac{31}{32}$ inches.	(*d*) 3.9974 ft.
(*e*) 10 feet $7\frac{5}{8}$ inches.	(*e*) 10.6354 ft.

2. Express the following in feet, inches, and fractions of an inch:

(*a*) 7.4756 feet.	(*a*) 7 ft. $5\frac{23}{32}$ in.
(*b*) 3.25 feet.	(*b*) 3 ft. 3 in.
(*c*) .8880 foot.	Ans. (*c*) $10\frac{21}{32}$ in.
(*d*) 5.437 feet.	(*d*) 5 ft. $5\frac{1}{4}$ in.
(*e*) 11.215 feet.	(*e*) 11 ft. $2\frac{19}{32}$ in.

3. Verify the following:

(*a*) $\frac{7}{16}$ inch = .4375 inch.
(*b*) $8\frac{27}{32}$ inches = 8.84375 inches.
(*c*) .231 inch = $\frac{7}{32}$ inch.
(*d*) 3.686 inches = $3\frac{11}{16}$ inches.

AREAS AND CIRCUMFERENCES OF CIRCLES

7. The area of a circle is equal to the square of the diameter, multiplied by .7854; and the circumference of a circle is equal to 3.1416 times the diameter. The results of these calculations for diameters in units and fractions from 0 to 100 are tabulated on pages 171 to 179, inclusive, of *Smoley's Tables*, Part 2. In the first column, headed Dia., are the diameters in units and fractions; in the second and third columns are the areas and circumferences, as indicated by the headings Area and Circum., respectively. The integers in the columns of diameters are the units in the given diameter, the fractions being annexed to the integer immediately above. Thus, if the integers represent inches, the values for a diameter of $29\frac{1}{4}$ inches are found on page 174 opposite the fraction $\frac{1}{4}$ just below the integer 29; the area is 671.96 square inches and the circumference is 91.8916 inches. If the radius is given, it is first multiplied by 2 to get the diameter.

8. The diameter corresponding to a given circumference or area may be found from the same tables. It is sufficiently

accurate for practical purposes to use the value in the column headed Circum. or Area, nearest to the given number; that is, interpolation is unnecessary. If the circumference contains a fraction, it must first be changed to a decimal before the number is sought in the tables. For example, suppose it is required to find the diameter corresponding to a circumference of $90\frac{1}{4}$ inches. The circumference expressed in inches and decimals is 90.25 inches; and the nearest value in the column headed Circum., on page 174, is 90.3208. The required diameter is $28\frac{3}{4}$ inches.

If the radius is wanted, take one-half of the diameter. Let it be required to find the radius of a circle whose area is 270 square inches. The nearest value in the column headed Area is 268.80 on page 173, and the corresponding diameter is $18\frac{1}{2}$ inches. The radius is, therefore, $\frac{1}{2}\times 18\frac{1}{2}$ or $9\frac{1}{4}$ inches.

EXAMPLES FOR PRACTICE

1. Find the area of a circular concrete column whose diameter is $24\frac{1}{2}$ inches. Ans. 471 sq. in.

2. What is the circumference of a circular tank having a radius of 2 feet $3\frac{5}{8}$ inches? Ans. 173.6 in.

3. What is the diameter of an engine piston if the required area is 105 square inches? Take the next larger $\frac{1}{2}$ inch. Ans. 12 in.

4. Find the radius of a circle whose circumference is 10 inches. Ans. $1\frac{19}{32}$ in.

PARALLEL TABLES

9. Arrangement of Tables.—The Parallel Tables of Logarithms and Squares occupy the first 300 pages of Part 1 of *Smoley's Tables*. For brevity, they will be called the Parallel Tables. In these tables are given the logarithms and squares of numbers by intervals of $\frac{1}{32}$ inch from 0 to 50 feet and by intervals of $\frac{1}{16}$ inch from 50 to 100 feet. The large figure at the top of each page represents a number of feet; for each foot up to 50 there are four pages, and for each foot from 50 to 100, two pages. Just beneath the number of feet is the number of inches from 1 to 11 by intervals of 1 inch.

The fractions of an inch are given in the left-hand column of each page, headed Fractions of an Inch. Under each number of inches are two columns, one of which contains the logarithms and the other the squares, as indicated by the respective headings, Log. and Square. The logarithms are for the numbers expressed in feet and decimals of a foot. The values in the columns of squares are in square feet and decimals of a square foot.

For example, let it be required to find the square of 35 feet $4\frac{1}{2}$ inches. Locate the heading 4″ on one of the pages marked 35′; then, in the column headed Square, under 4″ and in line with the fraction $\frac{1}{2}$, read 1251.3906, which is the desired value in square feet and a decimal of a square foot. Again, suppose the logarithm of 16 feet $7\frac{1}{8}$ inches is wanted. Look for the heading 7″ on one of the pages for 16′ and in the column headed Log. under that value, opposite the fraction $\frac{1}{8}$, read 1.21994.

10. The method of finding a length in feet, inches, and a fraction of an inch, from the Parallel Tables, when its logarithm or square is given, is the reverse of that just explained. The given quantity is first located in the tables in the column headed Log. or Square. The number of feet in the required length is then found at the top of the page, the number of inches at the top of the column, and the fraction of an inch opposite the given value in the column headed Fractions of an Inch. Thus, let it be required to find the distance whose logarithm is 1.35748. This logarithm is found in the column headed Log. on a page marked 22′; the number of inches, read at the top of the column, is 9; and the fraction of an inch opposite the given value is $\frac{5}{16}$. Hence, 1.35748 is the logarithm of 22 feet $9\frac{5}{16}$ inches.

In case the given number is not found in the table but lies between two printed values, the length corresponding to the nearest value in the tables may be taken. For instance, suppose that the length whose square is 1,848 is wanted. In the column of the tables headed Square, under 42′ 11″, the values 1847.8804 and 1848.1043 are found; the latter is

slightly closer to 1848. Since the fraction of an inch opposite 1848.1043 is $\frac{7}{8}$, the required length is 42 feet $11\frac{7}{8}$ inches.

11. Advantages of Tables.—The advantages of the Parallel Tables may be shown by finding the logarithm and the square of a number expressed in feet, inches, and a fraction of an inch without their aid. First, the given length must be reduced to feet and decimals of a foot. Then the logarithm is taken from tables of common logarithms and the square is calculated by arithmetic or logarithms. For example, let it be required to find the logarithm and the square of 9 feet $8\frac{3}{16}$ inches. The equivalent in feet and decimals of a foot is 9.6823 feet; and the logarithm, taken from tables of common logarithms, is 0.98598. The logarithm of the square of the given number equals $2 \times 0.98598 = 1.97196$ and the required square is 93.748. The required values can be taken directly from the Parallel Tables. The value of the square given in the tables, which is 93.7468, is slightly more accurate; the results differ because $8\frac{3}{16}$ inches is not precisely equal to .6823 foot and five-place logarithms are not exact.

12. By the arrangement of the Parallel Tables, the solution of triangles is greatly facilitated. Since the logarithm and the square of a number are placed side by side, both values can be taken from the tables at the same time. Moreover, the square of a number can be found when its logarithm is known, or vice versa, without first finding the number. It is generally unnecessary to interpolate when taking out a value. For example, suppose it is required to find the logarithm of a number whose square is 336.24. The nearest value in the column headed Square is 336.2066 and the corresponding logarithm, taken from the column headed Log., is 1.26330.

EXAMPLES FOR PRACTICE

1. Find the logarithm of 21 feet $7\frac{5}{8}$ inches. Ans. 1.33517

2. What is the square of 27 feet $\frac{1}{4}$ inch? Ans. 730.1254

3. What is the length whose square is (*a*) 653? (*b*) 87.21?

$$\text{Ans.}\begin{cases}(a)\ 25\text{ ft. }6\frac{21}{32}\text{ in.}\\(b)\ 9\text{ ft. }4\frac{1}{16}\text{ in.}\end{cases}$$

4. Find the length whose logarithm is (*a*) 0.86597; (*b*) 1.52079.

Ans. $\begin{cases} (a)\ 7 \text{ ft. } 4\frac{1}{8} \text{ in.} \\ (b)\ 33 \text{ ft. } 2\frac{3}{32} \text{ in.} \end{cases}$

5. Find the logarithm of the number whose square is 588.9.

Ans. 1.38504

6. Find the square of the number whose logarithm is 9.88861.

Ans. .5982

MULTIPLICATION TABLES

13. Rivet Spacing.—The Multiplication Table for Rivet Spacing, given in Part 1 of *Smoley's Tables* on pages 328 to 330, saves time and labor in computations for long rows of rivets. In this table, the number of spaces from 1 to 30 is at the top of a page; and the distance between rivets, from $1\frac{1}{8}$ to 6 inches by intervals of $\frac{1}{8}$, is in the left-hand column of each page, headed In. Numbers before the short dash indicate feet, and those following the dash, inches.

The table may be used in the solution of many common problems, such as (1) to find the distance between the extreme rivets when the number of rivets and the spacing are known, (2) to find the spacing when the number of rivets and the distance between the end rivets are given, (3) to find the number of rivets from the distance between the end rivets and the spacing. Similar problems dealing with the steel rods in reinforced concrete may also be solved by means of this table.

Example 1.—What is the distance between the extreme rivets in a set of 18 spaced $3\frac{1}{2}$ inches apart?

Solution.—Since there are 18 rivets, the number of spaces is 17. The distance between the end rivets, which is found on page 329 of the tables in the column headed 17 in line with $3\frac{1}{2}$ in the column headed In., is 4 ft. $11\frac{1}{2}$ in. Ans.

Example 2.—Sixteen rivets are to be spaced uniformly in a distance of 6 feet $6\frac{3}{4}$ inches. Find the distance between consecutive rivets.

Solution.—Since 16 rivets are to be used, there are 15 spaces. In the column headed 15, the distance 6 ft. $6\frac{3}{4}$ in. is found opposite $5\frac{1}{4}$ in the column headed In. Hence, the required spacing is $5\frac{1}{4}$ in. Ans.

EXAMPLE 3.—How many rivets spaced $4\frac{1}{2}$ inches apart can be placed in a distance of 10 feet 6 inches?

SOLUTION.—First the number $4\frac{1}{2}$ is located in a column of the tables headed In. Next, the horizontal line opposite $4\frac{1}{2}$ is followed until 10 ft. 6 in. is reached. This length is found on page 330 in the column headed 28. Therefore, there are 28 spaces and 29 rivets. Ans.

14. Spacing of Lattice Bars.—The purpose of the Multiplication Table for Spacing of Lattice Bars, given on pages 331 to 339 of *Smoley's Tables*, Part 1, is similar to that of the Multiplication Table for Rivet Spacing. The spacings, varying from 6 inches to 1 foot $11\frac{7}{8}$ inches by intervals of $\frac{1}{8}$ inch, are at the tops of the columns, and the number of spaces from 2 to 20 is given in the left-hand column of each page, headed No. Spaces. The following illustrative examples show how the table is used:

EXAMPLE 1.—Find the distance covered by 7 spaces of $10\frac{5}{8}$ inches each.

SOLUTION.—In the column headed $10\frac{5}{8}''$ on page 333 of the tables, the value opposite 7 in the column headed No. Spaces is 6 ft. $2\frac{3}{8}$ in. Ans.

EXAMPLE 2.—Fourteen spaces are to be used in a length of 17 feet $9\frac{1}{2}$ inches; find the spacing.

SOLUTION.—On line with 14 in the column headed No. Spaces, the value 17 ft. $9\frac{1}{2}$ in. is found on page 335 of the tables in the column headed $1'\,3\frac{1}{4}''$. Hence, the required spacing is 1 ft. $3\frac{1}{4}$ in. Ans.

EXAMPLES FOR PRACTICE

1. Find the distance between the end rivets in a set of 24 spaced $3\frac{1}{4}$ inches apart.
Ans. 6 ft. $2\frac{3}{4}$ in.

2. What should be the spacing between consecutive rivets if 12 are to be placed in a distance of 3 feet 8 inches?
Ans. 4 in.

3. How many rivets spaced $2\frac{1}{2}$ inches apart can be used in a distance of 1 foot $5\frac{1}{2}$ inches?
Ans. 8

4. What distance is covered by 11 spaces of 1 foot $8\frac{1}{4}$ inches?
Ans. 18 ft. $6\frac{3}{4}$ in.

5. How many $9\frac{1}{2}$-inch spaces can be used in a distance of 11 feet $10\frac{1}{2}$ inches?
Ans. 15

6. If 9 spaces are to be used in a length of 14 feet $7\frac{1}{2}$ inches, what should be the spacing?
Ans. 1 ft. $7\frac{1}{2}$ in.

BEVELS

PRELIMINARY EXPLANATIONS

15. Bevel Triangle.—As previously explained, angles in structural work are given by bevels. To indicate a bevel, as the bevel of AC, Fig. 2, with respect to AB, a small right triangle abc, called *bevel triangle*, is drawn, in which ab is parallel to AB and is marked 12″, while bc is perpendicular to AB and is marked $10\frac{7}{8}''$.

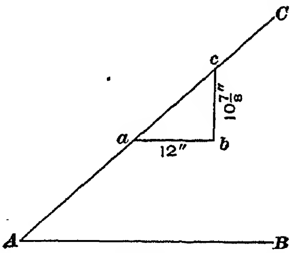

FIG. 2

As a matter of convenience, bevel triangles are so constructed that the longer leg is always 12 inches, the bevel itself being less than 12 inches. For angles greater than 45°, the tangent is greater than 1. Hence, if the bevel triangle were constructed by the method explained in Art. **2**, the bevel would exceed 12 inches. For instance, in Fig. 3, the angle BAC is 53° 25′, the natural tangent of which is 1.3473. If the bevel triangle were constructed with ab equal to 1 foot, or 12 inches, the side bc would be 1.3473 feet, or $16\frac{5}{32}$ inches. In order to avoid a bevel greater than 12 inches, the side bc is made equal to 12 inches and the side ab is given by the cotangent of the angle or, what is the same thing, by the tangent of the complementary angle. Thus, cot 53° 25′ = tan (90° − 53° 25′) = tan 36° 35′ = .7422. Since .7422 foot is equivalent to $8\frac{29}{32}$ inches, this number is considered as the bevel of AC, and the bevel triangle abc, Fig. 3, is marked

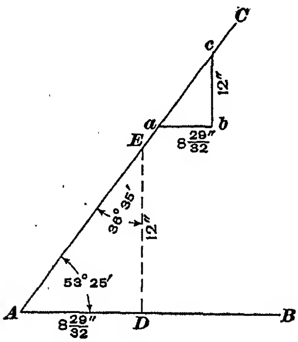

FIG. 3

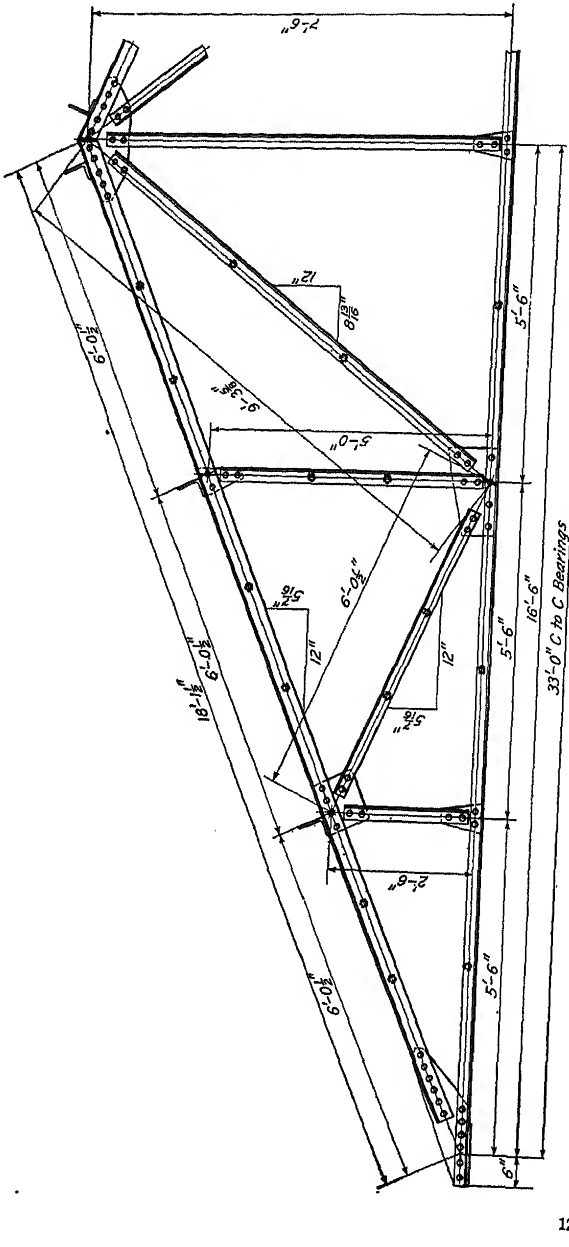
2'-6"
12"
8 13/16"
6'-0½"
9'-3 5/16"
5'-0"
5'-6"
6'-0½"
5 5/16"
12"
18'-1½"
6'-0½"
12"
5 5/16"
5'-6"
16'-6"
33'-0" C to C Bearings
2'-6"
6'-0½"
5'-6"
6"

FIG. 4

as shown. It will be noticed that, in this case, the leg of the bevel triangle indicating the bevel is parallel to the reference line, and the other leg, which is equal to 12 inches, is perpendicular to the reference line. To plot the angle BAC, Fig. 3, first lay off, to a suitable scale, AD equal to $8\frac{29}{32}$ inches and then on a perpendicular to AB, lay off, to the same scale, DE equal to 12 inches. The line AC through E makes an angle of 53° 25′ with AB.

16. Perpendicular and Parallel Bevels.—From the foregoing explanations, it is seen that there are two kinds of bevels, one indicating an angle less than 45° and the other corresponding to an angle greater than 45°. They can be distinguished only by the relative positions of the legs of the bevel triangle. When the angle is less than 45°, the leg indicating the bevel is perpendicular to the reference line; the bevel is then said to be a *perpendicular bevel.* If the angle is greater than 45°, the bevel is parallel to the reference line and is called a *parallel bevel.* Thus, in Fig. 2, the bevel $10\frac{7}{8}$ inches is a perpendicular bevel, and in Fig. 3, $8\frac{29}{32}$ inches is a parallel bevel. For an angle of 45°, each leg of the bevel triangle is marked 12 inches. In Fig. 4, in which part of a roof truss is represented, is shown an example of how bevels are marked in structural work.

BEVEL COMPUTATIONS

17. Classification of Problems.—Problems involving bevels may be divided into two groups. In one group are included those problems in which the bevel is to be determined from either an angle or a function of an angle, while in the second group the bevel is the given quantity, and either an angle or one of its functions is to be determined.

18. Determining Bevels Corresponding to Given Angles. When the angle from which a bevel is to be derived is less than 45°, the method of obtaining the bevel is as follows: First, from a table of natural functions, find the tangent of the angle, which is equal to the bevel expressed as a decimal of a foot. Then, the required result is found by reducing this decimal

to inches and a fraction, either by calculation or by means of a table of decimal equivalents. Finally, draw the bevel triangle and mark the bevel along the leg that is perpendicular to the reference line.

When the angle is greater than 45°, the procedure is the same, except that, in this case, the bevel is equivalent to the natural cotangent of the given angle and is marked along the leg of the bevel triangle that is parallel to the reference line. Instead of the cotangent of the given angle, the tangent of the complementary angle may be used.

EXAMPLE.—Find the bevel corresponding to an angle of 61° 13′.

SOLUTION.—Since the angle is greater than 45°, the bevel is a parallel one and is indicated by the natural cotangent of the angle, or the natural tangent of its complement. Thus, $\cot 61° 13' = \tan (90° - 61° 13') = \tan 28° 47' = .5494$. Since .5494 ft. is equivalent to $6\frac{19}{32}$ in., the bevel is $6\frac{19}{32}$ in. Ans.

19. Determining Bevels Corresponding to Functions of Angles.—To find the bevel when a function of an angle is given, the angle corresponding to the function is found first from either tables of natural functions or tables of logarithmic functions, according as the given value is a natural or logarithmic function. Then the bevel is obtained from the angle as explained in the preceding article.

EXAMPLE.—Find the bevel corresponding to the natural cosine .8350.

SOLUTION.—The corresponding angle is 33° 23′. Since the angle is less than 45°, the bevel is a perpendicular one and is equivalent to the natural tangent of the angle, which is .6590. The required bevel is, therefore, $7\frac{29}{32}$ in. Ans.

20. When the given function is a tangent that corresponds to an angle less than 45° or a cotangent corresponding to an angle greater than 45°, the bevel may be found directly without first determining the angle, since in each case the given function indicates the bevel. Thus, if the logarithmic tangent is known to be 9.75240, the natural tangent is .5655 and the bevel, which is the equivalent of .5655 foot, is $6\frac{25}{32}$ inches. Likewise, if the natural cotangent is .7188, the bevel, which is the equivalent of .7188 foot, is $8\frac{5}{8}$ inches.

The bevel in inches corresponding to a logarithmic tangent or cotangent may be found directly by means of the Parallel Tables. For instance, the nearest value in these tables corresponding to the logarithm 9.75240 is $6\frac{25}{32}$ inches.

21. Occasionally, a function of an angle is expressed as a ratio of two lengths instead of as a decimal. For instance, the tangent may be given as the ratio of 8 feet $4\frac{1}{4}$ inches to 12 feet $9\frac{1}{8}$ inches, that is, as $\frac{8 \text{ feet } 4\frac{1}{4} \text{ inches}}{12 \text{ feet } 9\frac{1}{8} \text{ inches}}$. In this case, the given numbers may be reduced to feet and decimals of a foot, or to inches and decimals of an inch, and the natural tangent obtained by division; or the logarithmic tangent may be determined by subtracting the logarithm of the denominator from that of the numerator. Thus, by the first method,

$$\frac{8 \text{ feet } 4\frac{1}{4} \text{ inches}}{12 \text{ feet } 9\frac{1}{8} \text{ inches}} = \frac{100.25 \text{ inches}}{153.125 \text{ inches}} = .6547$$

$$.6547 \text{ foot} = 7\tfrac{27}{32} \text{ inches}$$

By the second method, log (8 feet $4\frac{1}{4}$ inches) − log (12 feet $9\frac{1}{8}$ inches) = 0.92190 − 1.10586 = 9.81604. The bevel is then found, by the Parallel Tables, to be $7\frac{27}{32}$ inches.

22. Angles and Functions Corresponding to Bevels.—As previously explained, a perpendicular bevel represents the natural tangent of an angle less than 45° and a parallel bevel indicates the natural cotangent of an angle greater than 45°. Therefore, in finding an angle or a function corresponding to a given bevel, it must be known whether the bevel is perpendicular or parallel. In both cases, however, the first step is to express the bevel as a decimal of a foot. Then, for a perpendicular bevel, the decimal obtained is the natural tangent of the required angle, and for a parallel bevel, this decimal is the cotangent of the required angle. From either the tangent or the cotangent, the angle and its other functions may be determined by the usual method.

Example 1.—Find the natural cosine of the angle corresponding to a perpendicular bevel of $8\frac{3}{8}$ inches.

Solution.—The bevel reduced to a decimal of a foot is .6979. Since the bevel is a perpendicular one, the angle is less than 45° and the bevel is

its natural tangent. From the Tables of Natural Tangents and Cotangents, the angle whose tangent is .6979 is found to be 34° 55′. Finally, from the Tables of Natural Sines and Cosines, cos 34° 55′ = .8200. Ans.

EXAMPLE 2.—Find the logarithmic sine of the angle corresponding to a parallel bevel of $6\frac{5}{32}$ inches.

SOLUTION.—The bevel expressed as a decimal of a foot is .5130. Since the angle for a parallel bevel is greater than 45°, the number is the natural cotangent of the angle or the tangent of the complementary angle. The angle whose cotangent is .5130 is found to be nearly 62° 50′; then, log sin 62° 50′ = 9.94923. Ans.

The angle may also be found as follows: The angle whose tangent is .5130 is 27° 10′ and the required angle equals 90° − 27° 10′ = 62° 50′.

EXAMPLES FOR PRACTICE

1. Find the bevels corresponding to the following angles: (*a*) 26° 19′; (*b*) 54° 24′.

Ans. $\begin{cases} (a)\ 5\frac{15}{16} \text{ in. perpendicular} \\ (b)\ 8\frac{19}{32} \text{ in. parallel} \end{cases}$

2. Find the bevels corresponding to the following functions: (*a*) natural sine = .6473; (*b*) logarithmic cosine = 9.72010.

Ans. $\begin{cases} (a)\ 10\frac{3}{16} \text{ in. perpendicular} \\ (b)\ 7\frac{13}{32} \text{ in. parallel} \end{cases}$

3. For a perpendicular bevel of $7\frac{3}{8}$ inches, find: (*a*) the angle; (*b*) the natural cosine.

Ans. $\begin{cases} (a)\ 31° 35' \\ (b)\ .8519 \end{cases}$

4. For a parallel bevel of $5\frac{7}{16}$ inches, determine: (*a*) the angle; (*b*) the logarithmic sine.

Ans. $\begin{cases} (a)\ 65° 37' \\ (b)\ 9.95942 \end{cases}$

TABLES OF BEVELS

23. Description and Use of the Tables.—The bevel calculations treated in the preceding articles can be simplified greatly by the use of the Tables of Angles and Natural and Logarithmic Functions Corresponding to Bevels, which are given in Part 1 of *Smoley's Tables* on pages 304 to 327, inclusive. For the sake of brevity, these tables will be called Tables of Bevels.

The bevel is given by the large number, indicating inches, at the top of each page, in combination with the fractions in the left-hand column, which vary by $\frac{1}{32}$. In the line opposite the fraction is given, under the heading Angle, the value

of the corresponding angle in degrees, minutes, and seconds of arc. In the other columns of each left-hand page are the natural functions of the angle and on the right-hand page are the logarithmic functions of the same angle.

For instance, for a bevel of $3\frac{5}{16}$ inches, the corresponding angle, which is 15° 25′ 54″, and the functions of the angle are found on pages 310 and 311 of the tables on the horizontal line opposite $\frac{5}{16}$ in the left-hand column of each page. Thus, the natural tangent of the angle is on page 310 in the column headed Tang., and its value is 0.27604; the logarithmic sine is on page 311, in the column headed Sine, and its value is 9.42503. For a bevel of $8\frac{23}{32}$ inches, the angle is found in the right-hand columns on page 320 or page 321 of the tables, horizontally opposite $\frac{23}{32}$, and its value is 36° 00′ 03″; the natural secant is on page 320, in the column headed Sec., and is 1.23608; the logarithmic cosine is on page 321, in the column headed Cosine, and is 9.90795.

24. Finding Angles and Functions Corresponding to Parallel Bevels.—It will be noticed that in the Tables of Bevels the tabulations are carried out only for angles up to 45°. Therefore, the method of finding angles and functions described in the preceding article applies only to perpendicular bevels. For a parallel bevel, the corresponding angle in the Tables of Bevels is the complement of the required angle. Therefore, to determine the angle corresponding to a parallel bevel, find the angle in the Tables of Bevels corresponding to the given bevel and subtract this angle from 90°; the remainder is the required angle.

For example, suppose that the parallel bevel is $8\frac{29}{32}$ inches, as shown in Fig. 3, and it is required to find the corresponding angle. The angle in the tables corresponding to a bevel of $8\frac{29}{32}$ inches is found to be 36° 34′ 56″, say 36° 35′, and the required angle is 90° − 36° 35′ or 53° 25′.

It is sometimes required to find a function of an angle corresponding to a given parallel bevel. Although the angle itself cannot be found directly from the tables, any function of this angle can be taken from the tables without determining

the angle. The method is based on the principles that the sine of an angle equals the cosine of the complementary angle; the cosine of an angle equals the sine of the complementary angle; the tangent of an angle equals the cotangent of the complementary angle; the cotangent of an angle equals the tangent of the complementary angle; the secant of an angle equals the cosecant of the complementary angle; the cosecant of an angle equals the secant of the complementary angle. Therefore, for a parallel bevel, the sine of the angle corresponding to the bevel is found in the Tables of Bevels in the column headed Cosine, and the cosine is found in the column headed Sine. Similarly, the tangent is found in the column headed Cotang., the cotangent in the column headed Tang., the secant in the column headed Cosec., and the cosecant in the column headed Sec. For example, consider the case shown in Fig. 3. The natural sine of the angle BAC is found on page 320 of *Smoley's Tables* in the column headed Cosine, and is 0.80300; similarly, the logarithmic secant is found on page 321 in the column headed Cosec., and is 0.22477.

EXAMPLES FOR PRACTICE

Verify the following values:

1. For a perpendicular bevel of $7\frac{1}{8}$ inches:
   (*a*) Natural sine = .51054;
   (*b*) Logarithmic tangent = 9.77360.

2. For a perpendicular bevel of $5\frac{1}{2}$ inches:
   (*a*) Angle = 24° 37′ 25″;
   (*b*) Natural cosecant = 2.40007;
   (*c*) Logarithmic cosine = 9.95859.

3. For a parallel bevel of $6\frac{3}{4}$ inches:
   (*a*) Natural secant = 2.03973;
   (*b*) Logarithmic sine = 9.94031.

4. For a parallel bevel of $10\frac{5}{16}$ inches:
   (*a*) Angle = 49° 19′ 30″;
   (*b*) Logarithmic cotangent = 9.93418.

25. Finding Bevels Corresponding to Given Angles.—To find the bevel corresponding to an angle less than 45°, locate

the nearest value in the column of the tables headed Angle; then the number of inches in the bevel is at the top of the page and the fraction of an inch is horizontally opposite the angle. For instance, if the given angle is 40°, the nearest value in the tables is 39° 58′ 52″, which corresponds to a bevel of $10\frac{1}{16}$ inches.

It has been explained that for an angle greater than 45° the bevel is determined by the tangent of the complementary angle. Therefore, to find the bevel from the Tables of Bevels for an angle greater than 45°, the given angle must be subtracted from 90° and the resulting complement used. For example, if the angle is 63° 18′, its complement is 90° − 63° 18′, or 26° 42′, and the bevel corresponding to that angle is $6\frac{1}{32}$ inches. It must always be borne in mind, however, that when the angle is greater than 45°, the result is a parallel bevel.

26. Finding Bevels Corresponding to Given Functions. Frequently, an angle is given by one of its functions and it is required to find the bevel. If the angle corresponding to the function is less than 45°, there can always be found in the Tables of Bevels two values of this function between which the given number lies. Since the bevels in the tables vary by $\frac{1}{32}$ inch, the bevel corresponding to the given function can be determined to the nearest $\frac{1}{32}$ inch without interpolating between the two values, the printed value nearer to the given number being used. For example, suppose it is required to find the bevel corresponding to the angle whose natural cosine is .88625. In the column headed Cosine on page 316 of the Tables of Bevels, the values between which the given function lies are found to be .88691 and .88597, the nearer being .88597. Consequently, the required bevel is taken as $6\frac{9}{32}$ inches. Since the angle is less than 45°, the bevel is a perpendicular one.

27. When the angle corresponding to a given function is greater than 45°, the given number does not lie between two values of the function in the Tables of Bevels because the tables are prepared only for angles up to 45°. In this case, the bevel is parallel to the reference line; and a function of the

complementary angle, which is less than 45°, is considered. Although the complementary angle itself is not known, this function may be derived from the given function by one of the following relations in which B is any angle less than 90°:

$$\sin B = \cos (90° - B) \qquad (1)$$
$$\cos B = \sin (90° - B) \qquad (2)$$
$$\tan B = \cot (90° - B) \qquad (3)$$
$$\cot B = \tan (90° - B) \qquad (4)$$
$$\sec B = \csc (90° - B) \qquad (5)$$
$$\csc B = \sec (90° - B) \qquad (6)$$

Thus, if the given number is the sine of an angle greater than 45°, the same number is, by formula **1** or **2**, the cosine of the complementary angle. Therefore, to determine the bevel from the Tables of Bevels, the column of cosines may be used. Vice versa, if the given function is the cosine of an angle greater than 45°, it is considered as the sine of the complementary angle, which is less than 45°, and the bevel is determined from this sine. Similar reasoning is applied to the tangent and cotangent and to the secant and cosecant.

EXAMPLE 1.—Find the bevel corresponding to the angle whose logarithmic cosine is 9.63500.

SOLUTION.—The given function is less than 9.84949, which is the smallest value of the logarithmic cosine in the Tables of Bevels; therefore, the angle is greater than 45° and the bevel is a parallel one. Hence, the bevel is determined from the logarithmic sine of the complementary angle and is found to be $5\frac{3}{4}$ in., the nearest printed value in the column of logarithmic sines being 9.63560.

EXAMPLE 2.—What is the bevel corresponding to the angle whose logarithmic tangent is 0.15625?

SOLUTION.—The given number exceeds the highest value in the column of logarithmic tangents which is 0.00000. Consequently, the angle is greater than 45° and the bevel, which is a parallel one, is found by reference to the column of logarithmic cotangents to be $8\frac{3}{8}$ in.

EXAMPLE 3.—Find the bevel corresponding to the angle whose natural secant is 2.85000.

SOLUTION.—Since 2.85000 is greater than 1.41421, which is the highest value in the column of natural secants, the angle is greater than 45°; therefore, the bevel is a parallel one and is found from the natural cosecant of the complementary angle. The nearest value in the tables being 2.84800, the required bevel is $4\frac{1}{2}$ in.

EXAMPLES FOR PRACTICE

Find the bevels corresponding to the following values:

1. (*a*) Natural sine = .33603; (*b*) logarithmic secant = 0.05969.

Ans. $\begin{cases} (a)\ 4\frac{9}{32} \text{ in. perpendicular} \\ (b)\ 6\frac{3}{4} \text{ in. perpendicular} \end{cases}$

2. (*a*) Natural tangent = .85000; (*b*) logarithmic cosine = 9.93000.

Ans. $\begin{cases} (a)\ 10\frac{3}{16} \text{ in. perpendicular} \\ (b)\ 7\frac{13}{32} \text{ in. perpendicular} \end{cases}$

3. (*a*) Natural cosine = .63333; (*b*) natural tangent = 1.60000.

Ans. $\begin{cases} (a)\ 9\frac{13}{16} \text{ in. parallel} \\ (b)\ 7\frac{1}{2} \text{ in. parallel} \end{cases}$

4. (*a*) Logarithmic secant = 0.44444; (*b*) logarithmic cotangent = 9.85000.

Ans. $\begin{cases} (a)\ 4\frac{5}{8} \text{ in. parallel} \\ (b)\ 8\frac{1}{2} \text{ in. parallel} \end{cases}$

SOLUTION OF TRIANGLES IN STRUCTURAL WORK

RIGHT TRIANGLES

28. Classification of Problems.—A triangle has six parts: three sides and three angles. A triangle may be solved when three of its parts, one of which is a side, are known. In a right triangle, one of the angles is 90°; therefore, to solve a right triangle, it is necessary to know only two parts, one of which is a side. Thus, the two parts may be either two sides or one side and an acute angle.

When two sides of a right triangle are given, the known quantities may be the base and the altitude, the base and the hypotenuse, or the altitude and the hypotenuse. In each case, it is required to find the other side and the bevel of the hypotenuse. To facilitate further calculations, the logarithmic functions of the acute angles also are often required.

When the known parts of a right triangle are a side and an acute angle, the angle is usually given by the bevel of the hypotenuse; the side may be the base, the altitude, or the hypotenuse. It is then required to find the other two sides and sometimes the logarithmic functions of the angles.

29. Base and Altitude.—When one acute angle of a right triangle is known, the other can be found by subtracting the given angle from 90°. If, in a right triangle, the angle less than 45° is considered, the bevel of the hypotenuse will be a perpendicular one, while if the angle greater than 45° is considered, the hypotenuse will have a parallel bevel. Since the calculations for a perpendicular bevel are less confusing than those for a parallel bevel, it is usually convenient in the solution of triangles to use the formulas involving the angle less than 45°. Accordingly, the longer leg of a triangle is generally considered as the base, and the shorter leg as the altitude. The 12-inch leg of the bevel triangle is, therefore, parallel to the base, and the leg of the bevel triangle that indicates the bevel is parallel to the altitude. In the solutions of right triangles treated in this Section, all the bevels are perpendicular ones and the base is always greater than the altitude.

30. Case I.—*Given the base and the altitude; required the hypotenuse and the bevel of the hypotenuse.* This is the most common problem in structural work. The angle in degrees is rarely needed; but very often, for use in other calculations, the logarithmic functions of the angle are wanted. Such calculations are usually necessary in solving a net of triangles,

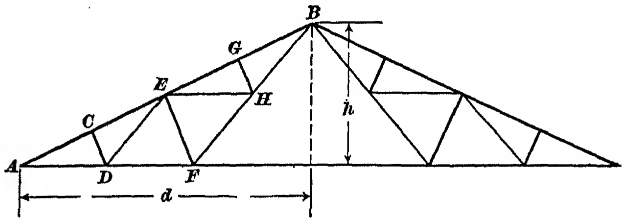

Fig. 5

as, for example, in the roof truss shown in Fig. 5. The height h and the half span d are usually known; and the length and bevel of the rafter AB can be found without first determining the angle A. But, as will be shown later, to find the lengths and directions of the *diagonals*, such as BF, EF, and DE, and also for the purpose of checking the work, the logarithmic functions of the angle A are needed.

The method of solving this problem with and without the aid of the Parallel Tables is shown in the following example:

EXAMPLE.—In Fig. 6, $b=40$ feet $6\frac{3}{4}$ inches and $a=12$ feet $4\frac{1}{2}$ inches. Find c, the bevel s, and the logarithmic functions of angle A.

SOLUTION.—When *Smoley's Tables* are not at hand, the first step in the solution is to reduce the dimensions of a and b to feet and decimals of a foot. The next step is to find the angle A in degrees and minutes from the relation, $\log \tan A = \log a - \log b$. Then the bevel, expressed as a decimal, is determined from $\log \tan A$, and the hypotenuse c may be calculated by the formula, $\log c = \log a - \log \sin A$. Since the answers for s and c have been obtained in decimals, their equivalents in inches and fractions of an inch must be found.

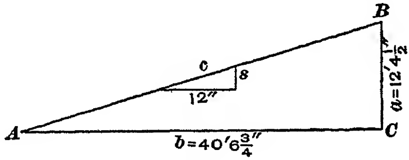

FIG. 6

It is also required to find the logarithmic functions of the angle A. The values of $\log \tan A$ and $\log \sin A$ have been found already; any other logarithmic function may be determined from the tables or by one of the following formulas, which are derived from the definitions of the functions.

$$\begin{aligned}
\log \cos A &= \log b - \log c\\
\log \cot A &= \log b - \log a\\
\log \sec A &= \log c - \log b\\
\log \csc A &= \log c - \log a
\end{aligned}$$

When the angle contains seconds, it is generally easier to use the formulas than to interpolate in the tables. The numerical work follows:

$$b = 40 \text{ ft. } 6\tfrac{3}{4} \text{ in.} = 40.563 \text{ ft. and } a = 12 \text{ ft. } 4\tfrac{1}{2} \text{ in.} = 12.375 \text{ ft.}$$

$$\begin{array}{rl}
\log a &= 1.09255\\
\log b &= \underline{1.60813}\\
\log s = \log \tan A &= 9.48442\\
\text{Then } A &= 16°\ 58'\\
\text{and } s &= .3051 \text{ ft.} = 3\tfrac{21}{32} \text{ in. Ans.}
\end{array}
\qquad
\begin{array}{rl}
\log a &= 1.09255\\
\log \sin A &= \underline{9.46511}\\
\log c &= 1.62744\\
c &= 42.407 \text{ ft.}\\
&= 42 \text{ ft. } 4\tfrac{7}{8} \text{ in.}\\
& \text{Ans.}
\end{array}$$

In this case the functions of A may be taken from the tables very closely without interpolating, since A is very nearly $16°\ 58'$. For illustration, however, they will be calculated here. Thus,

$$\begin{aligned}
\log \cos A &= 1.60813 - 1.62744 = 9.98069\\
\log \cot A &= 1.60813 - 1.09255 = 0.51558\\
\log \sec A &= 1.62744 - 1.60813 = 0.01931\\
\log \csc A &= 1.62744 - 1.09255 = 0.53489
\end{aligned}$$

SOLUTION WITH PARALLEL TABLES.—The given values are $b=40$ ft. $6\frac{3}{4}$ in. and $a=12$ ft. $4\frac{1}{2}$ in. If *Smoley's Tables* are used, it is more convenient

to find c by means of the relation $c^2 = a^2 + b^2$. The values of a^2 and b^2 can be taken directly from the tables without first reducing inches to decimals of a foot, and the value of c in feet and inches corresponding to c^2 can also be found at once. The bevel s is determined by the relation $\log s = \log \tan A = \log a - \log b$; but $\log a$ and $\log b$ may be taken from the Parallel Tables at the same time that a^2 and b^2 are found, and s, expressed in inches, can also be taken directly from the tables. For the purpose of determining certain functions of the angle A, and for checking the work, $\log c$ and s^2 are also needed. Their values can be taken from the Parallel Tables at the same time that c and s are found from c^2 and $\log s$, respectively.

By definition, $\log \tan A$ is equal to $\log s$, and the other functions of the angle A may be found by the following formulas:

$$\begin{aligned}
\log \sin A &= \log a - \log c \\
\log \cos A &= \log b - \log c \\
\log \cot A &= \log b - \log a \\
\log \sec A &= \log c - \log b \\
\log \csc A &= \log c - \log a
\end{aligned}$$

The numerical work follows:

$$\begin{aligned}
\log a &= 1.09255 & a^2 &= 153.1406 \\
\log b &= \underline{1.60812} & b^2 &= \underline{1645.3164} \\
\log \tan A = \log s &= 9.48443 & c^2 &= 1798.4570
\end{aligned}$$

From the Parallel Tables, the value of c corresponding to c^2 is 42 ft. $4\frac{29}{32}$ in., and $\log c = 1.62746$.

Also, the value of s corresponding to $\log s$ is $3\frac{21}{32}$ in. and $s^2 = .0928$.

The other functions of the angle A are:

$$\begin{aligned}
\log \sin A &= 1.09255 - 1.62746 = 9.46509 \\
\log \cos A &= 1.60812 - 1.62746 = 9.98066 \\
\log \cot A &= 1.60812 - 1.09255 = 0.51557 \\
\log \sec A &= 1.62746 - 1.60812 = 0.01934 \\
\log \csc A &= 1.62746 - 1.09255 = 0.53491
\end{aligned}$$

An easy method of checking the values of s and c is as follows: It will be observed that in the bevel triangle the base is one foot and the altitude is s. If the hypotenuse is denoted by h, then $h^2 = 1^2 + s^2 = 1 + s^2$. In this case, s^2 is known to be .0928 and, therefore, $h^2 = 1 + .0928 = 1.0928$. The value of h is then found from the Parallel Tables to be 1 ft. $\frac{17}{32}$ in.

The hypotenuse is also equal to the base multiplied by the secant of the angle adjacent to the base; hence, in the bevel triangle, $h = 1 \times \sec A = \sec A$, whence $\log h = \log \sec A$. The value of $\log \sec A$ is 0.01934 and the corresponding value of h is again found to be 1 ft. $\frac{17}{32}$ in.

Thus, h is obtained by two methods; the value of s is used in one method, and, since $\log \sec A = \log c - \log b$, the value of c is used in the other. The same result is found for h in both cases, and, consequently, the values of c and s are shown to be correct.

In practice it is customary to check the work as soon as possible to avoid carrying errors through subsequent calculations. Therefore, as soon as log c and s are found, log sec A is determined and the work is checked, as just shown. The other functions of angle A are calculated afterwards.

The values involved may be conveniently arranged as shown in Table I. The letters N, L, and S indicate, respectively, the numerical value, the logarithm, and the square of the part given in the first column in the table.

It will be noticed that the value of c was obtained as the nearest number in the tables corresponding to c^2, and, therefore, it is only approximate.

TABLE I

VALUES USED IN SOLUTION

	N	L	S
c	42 ft. $4\frac{29}{32}$ in.	1.62746	1,798.4570
a	12 ft. $4\frac{1}{2}$ in.	1.09255	153.1406
b	40 ft. $6\frac{3}{4}$ in.	1.60812	1,645.3164
$s=\tan A$	$3\frac{21}{32}$ in.	9.48443	.0928
$h=\sec A$	1 ft. $\frac{17}{32}$ in.	0.01934	1.0928

Consequently, log c and the logarithmic functions of the angle derived from c are also approximate. However, since the values in the tables vary by $\frac{1}{32}$ inch, and the nearest $\frac{1}{32}$ is used, the difference between the true value of c and the one taken from the tables cannot exceed $\frac{1}{64}$ inch. When the approximate values of the functions are used for solving a triangle in which the hypotenuse is smaller than c, the error will not be increased. Hence, the approximate values of c and of the logarithmic functions are sufficiently accurate for solving triangles formed by the members of a frame when, as is usually the case, the dimensions of these members are smaller than the main dimensions used in deriving the approximate values.

31. Case II.—*Given the base and the hypotenuse; to find:* (*a*) *the altitude;* (*b*) *the bevel of the hypotenuse; and* (*c*) *the logarithmic functions of an angle.*

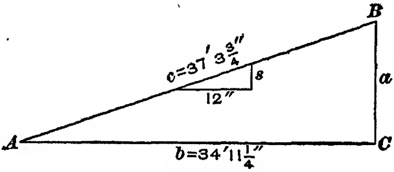

Fig. 7

EXAMPLE.—In Fig. 7, $c=37$ feet $3\frac{3}{4}$ inches and $b=34$ feet $11\frac{1}{4}$ inches. Find a, the bevel s, and the logarithmic functions of the angle A.

SOLUTION.—First, a is determined by the relation $a^2=c^2-b^2$. The values of c^2 and b^2 are taken directly from the Parallel Tables. Their difference is a^2; then the corre-

sponding value of a in feet and inches is found from the same tables. Since $\log a$ is needed in determining the functions of the angle A, its value is taken from the tables at the same time that a is found from a^2.

By definition, $\sec A = \frac{c}{b}$, whence $\log \sec A = \log c - \log b$. The values of $\log c$ and $\log b$ are taken from the Parallel Tables at the same time that c^2 and b^2 are found; their difference is $\log \sec A$. The bevel s corresponding to this value of $\log \sec A$ is then found from the Tables of Bevels.

The work may be arranged as follows:

$$\begin{array}{rlcrl} \log c &= 1.57185 & & c^2 &= 1392.2227 \\ \log b &= \underline{1.54329} & & b^2 &= \underline{1220.6289} \\ \log \sec A &= 0.02856 & & a^2 &= 171.5938 \end{array}$$

From the Parallel Tables, $a = 13$ ft. $1\frac{3}{16}$ in., and $\log a = 1.11724$. From the Tables of Bevels, the bevel, corresponding to $\log \sec A = 0.02856$, is $s = 4\frac{1}{2}$ in.

As a check, s is determined from the relation $\log s = \log \tan A = \log a - \log b$, as follows:

$$\begin{array}{rl} \log a &= 1.11724 \\ \log b &= \underline{1.54329} \\ \log s &= 9.57395 \end{array}$$

Since s is again found to be $4\frac{1}{2}$ in., the work is correct.

The other functions of the angle A may be found as explained in Case I.

Thus,
$$\begin{aligned} \log \sin A &= \log a - \log c = 1.11724 - 1.57185 = 9.54539 \\ \log \cos A &= \log b - \log c = 1.54329 - 1.57185 = 9.97144 \\ \log \cot A &= \log b - \log a = 1.54329 - 1.11724 = 0.42605 \\ \log \csc A &= \log c - \log a = 1.57185 - 1.11724 = 0.45461 \end{aligned}$$

The work may also be arranged as in Table II.

TABLE II

VALUES USED IN SOLUTION

	N	L	S
a	13 ft. $1\frac{3}{16}$ in.	1.11724	171.5938
c	37 ft. $3\frac{3}{4}$ in.	1.57185	1,392.2227
b	34 ft. $11\frac{1}{4}$ in.	1.54329	1,220.6289
$\sec A$		0.02856	
$s = \tan A$	$4\frac{1}{2}$ in.	9.57395	

32. Case III.—*Given the altitude and the hypotenuse; to find: (a) the base; (b) the bevel of the hypotenuse; and (c) the logarithmic functions of an angle.*

EXAMPLE.—In Fig. 8, $a=10$ feet $3\frac{1}{2}$ inches and $c=21$ feet $6\frac{7}{8}$ inches. Find b, the bevel s, and the logarithmic functions of the angle A.

SOLUTION.—The method of solution is similar to that of the example in the preceding case. The base b is found from the relation $b^2=c^2-a^2$; log b may be taken from the Parallel Tables at the same time that b is found from its square. The value of log csc A is determined by the relation log csc A = log c − log a, and the corresponding bevel is taken from the Tables of Bevels. The other functions of the angle A are computed from the sides of the triangle as before.

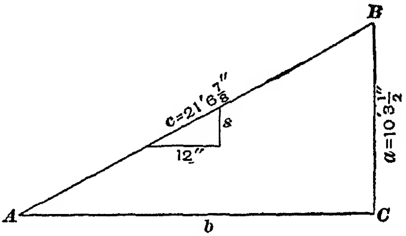

FIG. 8

The computations may be arranged as follows:

$$\begin{array}{rl} \log c = & 1.33391 \\ \log a = & \underline{1.01249} \\ \log \csc A = & 0.32142 \end{array} \qquad \begin{array}{rl} c^2 = & 465.3907 \\ a^2 = & \underline{105.9184} \\ b^2 = & 359.4723 \end{array}$$

From the Parallel Tables, $b=18$ ft. $11\frac{17}{32}$ in. and log $b=1.27786$.

From the Tables of Bevels, the value of s, corresponding to log csc A $=0.32142$, is $6\frac{1}{2}$ in. Ans.

The other functions of the angle A are obtained as follows:

$$\log \sin A = \log a - \log c = 1.01249 - 1.33391 = 9.67858$$
$$\log \cos A = \log b - \log c = 1.27786 - 1.33391 = 9.94395$$
$$\log \tan A = \log a - \log b = 1.01249 - 1.27786 = 9.73463$$
$$\log \cot A = \log b - \log a = 1.27786 - 1.01249 = 0.26537$$
$$\log \sec A = \log c - \log b = 1.33391 - 1.27786 = 0.05605$$

The work may be checked by determining the bevel from the relation log s = log tan $A=9.73463$. Since the corresponding value of s is $6\frac{1}{2}$ in., the work is correct.

The results may also be given as in Table III.

TABLE III

VALUES USED IN SOLUTION

	N	L	S
b	18 ft. $11\frac{17}{32}$ in.	1.27786	359.4723
c	21 ft. $6\frac{7}{8}$ in.	1.33391	465.3907
a	10 ft. $3\frac{1}{2}$ in.	1.01249	105.9184
csc A		0.32142	
s = tan A	$6\frac{1}{2}$ in.	9.73463	

EXAMPLES FOR PRACTICE

1. If the altitude a of a right triangle is 10 feet 8 inches and the base b is 32 feet 3 inches, find the hypotenuse c, its bevel s, and the logarithmic sine of the angle A.

$$\text{Ans.}\begin{cases} c = 33 \text{ ft. } 11\tfrac{5}{8} \text{ in.} \\ s = 3\tfrac{31}{32} \text{ in.} \\ \log \sin A = 9.49695 \end{cases}$$

2. The base b and the hypotenuse c of a right triangle are 23 feet $7\frac{1}{4}$ inches and 25 feet $1\frac{1}{8}$ inches, respectively. Find the altitude a, the bevel s, and the logarithmic cosecant of the angle A.

$$\text{Ans.}\begin{cases} a = 8 \text{ ft. } 6\tfrac{7}{32} \text{ in.} \\ s = 4\tfrac{11}{32} \text{ in.} \\ \log \csc A = 0.46922 \end{cases}$$

3. If the altitude a of a right triangle is 14 feet $5\frac{1}{8}$ inches and the hypotenuse c is 29 feet $4\frac{1}{2}$ inches, find the base b, the bevel s, and the logarithmic secant of the angle A.

$$\text{Ans.}\begin{cases} b = 25 \text{ ft. } 7\tfrac{1}{16} \text{ in.} \\ s = 6\tfrac{25}{32} \text{ in.} \\ \log \sec A = 0.05993 \end{cases}$$

---

33. Case IV.—*Given the base and the bevel of the hypotenuse; required: (a) the altitude; (b) the hypotenuse; and (c) the logarithmic functions of an angle.*

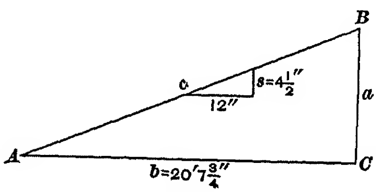

FIG. 9

EXAMPLE.—In Fig. 9, $b = 20$ feet $7\frac{3}{4}$ inches and $s = 4\frac{1}{2}$ inches. Find a, c, and the logarithmic functions of angle A.

SOLUTION.—In this case, the bevel s is given and, therefore, the logarithmic functions of the angle can be taken directly from the Tables of Bevels. Thus, from page 313, $\log \sin A = 9.54546$, $\log \cos A = 9.97143$, $\log \tan A = 9.57403$, $\log \cot A = 0.42597$, $\log \sec A = 0.02857$, and $\log \csc A = 0.45454$. Then the unknown sides are found by means of the formulas $a = b \tan A$ and $c = b \sec A$; hence,

$$\log a = \log b + \log \tan A$$

and

$$\log c = \log b + \log \sec A$$

The value of $\log b$ is taken from the Parallel Tables and a and c are found from their logarithms by reference to the same tables.

The calculations are conveniently arranged in the following form: The value of $\log b$ is written only once with $\log \tan A$ above and $\log \sec A$

below. Then the addition is performed upwards for log a and downwards for log c.

$$
\begin{aligned}
\log a &= \underline{0.88886} \quad a = 7 \text{ ft. } 8\tfrac{29}{32} \text{ in.} \quad \text{Ans.}\\
\log\tan A &= 9.57403\\
\log b &= 1.31483\\
\log\sec A &= \underline{0.02857}\\
\log c &= 1.34340 \quad c = 22 \text{ ft. } \tfrac{19}{32} \text{ in.} \quad \text{Ans.}
\end{aligned}
$$

As a check on the computed values, the relation $a^2+b^2=c^2$ is applied. The value of b^2 is taken from the Parallel Tables with log b, and the value of a^2 is taken out when a is found from log a.

$$
\begin{aligned}
a^2 &= 59.9415\\
b^2 &= \underline{426.2504}\\
c^2 &= 486.1919
\end{aligned}
$$

The value of c from the Parallel Tables is 22 ft. $\tfrac{19}{32}$ in.; therefore, the work is correct.

34. Case V.—*Given the altitude and the bevel of the hypotenuse; to find: (a) the base; (b) the hypotenuse; and (c) the logarithmic functions of an angle.*

EXAMPLE.—In Fig. 10, a is 8 feet $9\tfrac{1}{2}$ inches and s is $8\tfrac{1}{8}$ inches. Find b, c, and the logarithmic functions of angle A.

SOLUTION.—This problem is similar to that of Case IV. The logarithmic functions of the angle A can be taken directly from the Tables of Bevels. Thus, log sin A $=9.74870$, log cos $A=9.91806$, log tan $A=9.83064$, log cot $A=0.16936$, log sec $A=0.08194$, and log csc $A=0.25130$. Then, the base b may be determined by the formula $b=a$ cot A, whence log $b=$ log $a+$log cot A, and the hypotenuse c by the formula $c=a$ csc A, from which log $c=$ log $a+$log csc A. As a check, a^2+b^2 should be equal to c^2. The work for determining the lengths of the sides is arranged as follows:

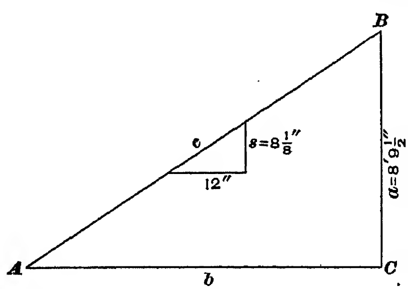

FIG. 10

$$
\begin{aligned}
\log b &= \underline{1.11343} \quad b = 12 \text{ ft. } 11\tfrac{13}{16} \text{ in.} \quad \text{Ans.}\\
\log\cot A &= 0.16936\\
\log a &= 0.94407\\
\log\csc A &= \underline{0.25130}\\
\log c &= 1.19537 \quad c = 15 \text{ ft. } 8\tfrac{5}{32} \text{ in.} \quad \text{Ans.}
\end{aligned}
$$

As a check,

$$a^2 = \ \ 77.2934$$
$$b^2 = 168.5940$$
$$c^2 = 245.8874$$

From the Parallel Tables, $c = 15$ ft. $8\frac{5}{32}$ in.; hence, the work is correct.

35. Case VI.—*Given the length and bevel of the hypotenuse; to find: (a) the base; (b) the altitude; and (c) the logarithmic functions of an angle.*

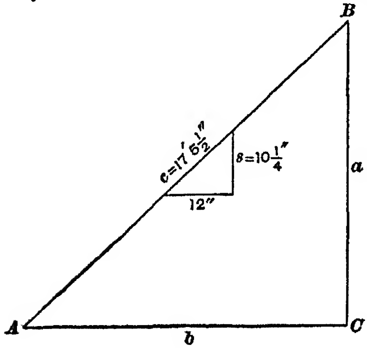

FIG. 11

EXAMPLE.—In Fig. 11, $c = 17$ feet $5\frac{1}{2}$ inches and $s = 10\frac{1}{4}$ inches. Find a, b, and the logarithmic functions of the angle A.

SOLUTION.—As in Cases IV and V, the logarithmic functions of the angle A may be taken directly from the Tables of Bevels. Thus, $\log \sin A = 9.81257$, $\log \cos A = 9.88103$, $\log \tan A = 9.93154$, $\log \cot A = 0.06846$, $\log \sec A = 0.11897$, and $\log \csc A = 0.18743$. For determining the unknown sides, use the formulas $a = c \sin A$ and $b = c \cos A$, whence $\log a = \log c + \log \sin A$ and $\log b = \log c + \log \cos A$. As a check, $a^2 + b^2 = c^2$. The calculations for the lengths of the sides may be arranged as follows:

$$\log a = 1.05457 \quad a = 11 \text{ ft. } 4\tfrac{1}{16} \text{ in. Ans.}$$
$$\log \sin A = 9.81257$$
$$\log c = 1.24200$$
$$\log \cos A = 9.88103$$
$$\log b = 1.12303 \quad b = 13 \text{ ft. } 3\tfrac{5}{16} \text{ in. Ans.}$$

As a check,

$$a^2 = 128.5625$$
$$b^2 = 176.2533$$
$$c^2 = 304.8158$$

From the Parallel Tables, $c = 17$ ft. $5\frac{1}{2}$ in.; therefore, the work is correct.

NOTE.—It sometimes happens that the given distances are in even figures. In such cases the use of the natural functions given on the left-hand pages in the Tables of Bevels simplifies the numerical work. For example, suppose that the base b of a right triangle is 20 feet and the perpendicular bevel is $3\frac{1}{2}$ in. From the Tables of Bevels, $\tan A = 0.29167$ and $\sec A = 1.04167$. Hence, $a = b \tan A = 20 \times .29167 = 5.833$ ft. $= 5$ ft. 10 in., and $c = b \sec A = 20 \times 1.04167 = 20.833$ ft. $= 20$ ft. 10 in.

EXAMPLES FOR PRACTICE

1. The base b of a right triangle is 22 feet 6 inches and the bevel s is $3\frac{1}{4}$ inches. Find the hypotenuse c, the altitude a, and the logarithmic sine of angle A.

$$\text{Ans.}\begin{cases} c = 23 \text{ ft. } 3\frac{23}{32} \text{ in.} \\ a = 6 \text{ ft. } 1\frac{1}{8} \text{ in.} \\ \log \sin A = 9.41733 \end{cases}$$

2. The hypotenuse c of a right triangle is 13 feet 3 inches and the bevel s is $4\frac{3}{8}$ inches. Find the altitude a, the base b, and the logarithmic tangent of angle A.

$$\text{Ans.}\begin{cases} a = 4 \text{ ft. } 6\frac{15}{32} \text{ in.} \\ b = 12 \text{ ft. } 5\frac{3}{8} \text{ in.} \\ \log \tan A = 9.56180 \end{cases}$$

---

36. Solution of Frame.—By combining the methods explained in the preceding articles, the lengths and bevels of the members of a frame can readily be found.

EXAMPLE.—In the roof truss shown in Fig. 12, d = 34 feet 3 inches and h = 14 feet 6 inches. The distances AC, CE, EG, and GB are equal and

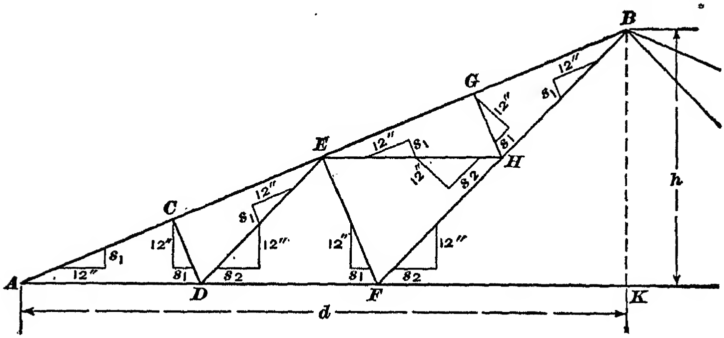

FIG. 12

the members CD, EF, and GH are perpendicular to AB. Find the lengths and bevels of all the members.

SOLUTION.—In the right triangle BAK, the base and the altitude are known and therefore the hypotenuse AB, its bevel s_1, and the logarithmic functions of the angle A may be found as explained in Art. **30**.

$$\begin{array}{rlrl} \log h &= 1.16137 & h^2 &= 210.2500 \\ \log d &= 1.53466 & d^2 &= 1173.0625 \\ \hline \log \tan A = \log s_1 &= 9.62671 & \overline{AB}^2 &= 1383.3125 \end{array}$$

From the Parallel Tables, AB = 37 ft. $2\frac{5}{16}$ in. and $\log AB$ = 1.57046. Since the other members of the truss are all shorter than AB, the value of

log AB corresponding to the nearest value of $\overline{AB}^2$ in the tables may be used, and interpolation is unnecessary.

Also, $s_1 = 5\frac{3}{32}$ in. and $s_1^2 = .1802$

As a check, log sec A = log AB − log d = 1.57046 − 1.53466 = 0.03580 and the corresponding number in the Parallel Tables is 1 ft. $1\frac{1}{32}$ in. Also, $\sec^2 A = 1 + s_1^2 = 1 + .1802 = 1.1802$, and the corresponding value is likewise found to be 1 ft. $1\frac{1}{32}$ in. The work is, therefore, correct.

The other logarithmic functions of the angle A will not be needed in this example.

Since AB is divided into four equal parts at C, E, and G, each is equal to $\frac{1}{4}$ AB = 9 ft. $3\frac{9}{16}$ in.

The members CD, EF, and GH are perpendicular to AB. Consequently, the angle that each of these members makes with the vertical is the same as the angle between AB and the horizontal. The bevels of CD, EF, and GH with respect to AK are, therefore, equal to s_1, but they are parallel bevels.

Next, the triangle AEF is solved. In this triangle the base AE is equal to $\frac{1}{2}$ AB = 18 ft. $7\frac{5}{32}$ in., and the logarithmic tangent and secant of angle A are known from previous computations. Then $EF = AE \tan A$ and $AF = AE \sec A$; hence, log EF = log AE + log tan A and log AF = log AE + log sec A.

$$\begin{aligned}\log EF &= \underline{0.89614} \quad EF = 7 \text{ ft. } 10\tfrac{15}{32} \text{ in.}\\ \log\tan A &= 9.62671\\ \log AE &= 1.26943\\ \log\sec A &= \underline{0.03580}\\ \log AF &= 1.30523 \quad AF = 20 \text{ ft. } 2\tfrac{11}{32} \text{ in.}\end{aligned}$$

As a check,

$$\begin{aligned}\overline{EF}^2 &= 61.9746\\ \overline{AE}^2 &= \underline{345.8244}\\ \overline{AF}^2 &= 407.7990\end{aligned}$$

From the Parallel Tables, AF = 20 ft. $2\frac{11}{32}$ in. Therefore, the work is correct.

From the values already determined, all the diagonals may now be found in the following manner: The right triangles AEF and BEF are equal because the leg EF is common to both and $AE = EB$; hence, $BF = AF$ = 20 ft. $2\frac{11}{32}$ in. The right triangles ACD and AEF are similar because they have the common acute angle A; since $AC = \frac{1}{2}$ AE, it follows that $AD = \frac{1}{2}$ AF = 10 ft. $1\frac{3}{16}$ in., and $CD = \frac{1}{2}$ EF = 3 ft. $11\frac{1}{4}$ in. Obviously, $DF = AD$. Next, by inspection of the figure, it is seen that $GH = CD$ = 3 ft. $11\frac{1}{4}$ in. and $DE = EH = BH = HF = AD$ = 10 ft. $1\frac{3}{16}$ in.

Finally, $FK = AK - AF$ = 34 ft. 3 in. − 20 ft. $2\frac{11}{32}$ in. = 14 ft. $\frac{21}{32}$ in.

As a check, $h^2 + \overline{FK}^2 = \overline{BF}^2$. From the Parallel Tables, $h^2 = 210.2500$, and $\overline{FK}^2 = 197.5342$. Then, $\overline{BF}^2 = 210.2500 + 197.5342 = 407.7842$, and

the nearest number in the tables is 20 ft. $2\frac{5}{16}$ in. This result agrees closely enough with the value 20 ft. $2\frac{11}{32}$ in. which was previously obtained. Since BK is longer than FK, it follows that the angle BFK is greater than 45°. Hence, the bevel of FB is found by the relation $s_2 = \cot BFK = \frac{FK}{BK}$.

$$\begin{aligned} \log FK &= 1.14782 \\ \log BK &= 1.16137 \\ \hline \log s_2 &= 9.98645 \quad s_2 = 11\tfrac{5}{8} \text{ in.} \end{aligned}$$

Member DE joins the mid-points of AB and AF and is therefore parallel to FB; hence, the bevel of DE with reference to AF is also equal to s_2.

In laying out the joint at E, the bevels of ED and EH with respect to AB will be needed. Since the triangles CED and GEH are equal to CAD, the angles CED and GEH are equal to CAD; therefore, the bevels of ED and EH are equal to s_1. Similarly, the bevel of BH with reference to AB is s_1.

The bevels of HG and HE with respect to FB are required for laying out the joint at H. The triangles DEF and HEF are equal, the angles EDF and EHF are equal, and, therefore, the bevel of HE is equal to s_2. The triangles ACD and BGH are also equal, the angles ADC and BHG are equal, and the bevel of HG is s_1.

EXAMPLE FOR PRACTICE

If h, Fig. 12, is 13 feet $8\frac{1}{2}$ inches and d is 30 feet $4\frac{1}{4}$ inches, find the lengths and bevels of the members of the frame.

$$\text{Ans.} \begin{cases} s_1 = 5\frac{13}{32} \text{ in.} \\ AB = 33 \text{ ft. } 3\frac{11}{16} \text{ in.} \\ AF = BF = 18 \text{ ft. } 3\frac{9}{32} \text{ in.} \\ AC = CE = EG = GB = 8 \text{ ft. } 3\frac{15}{16} \text{ in.} \\ EF = 7 \text{ ft. } 6\frac{1}{4} \text{ in.} \\ AD = DE = EH = DF = FH = HB = 9 \text{ ft. } 1\frac{5}{8} \text{ in.} \\ CD = GH = 3 \text{ ft. } 9\frac{1}{8} \text{ in.} \\ s_2 = 10\frac{9}{16} \text{ in.} \end{cases}$$

GRAPHIC SOLUTION OF RIGHT TRIANGLES

37. When two sides of a right triangle are known, the third side may be taken directly from the diagrams on pages 301b to 301k of *Smoley's Tables*, Part 1. There are four diagrams, all of which are similar in principle but are applied to different conditions. In these diagrams, the lengths of the legs are given on the horizontal and the vertical lines and the length

of the hypotenuse is determined from the circular arcs. A detailed description of the diagrams is given on pages 301b and 301f of *Smoley's Tables*, but a few explanations and examples will be added here.

In the diagram on pages 301b and 301c, the smallest divisions in all directions represent eighths of a unit; if the unit is an inch, the results can be read directly to the nearest $\frac{1}{8}$ inch and can be estimated to $\frac{1}{16}$ or $\frac{1}{32}$ inch. In the diagram on pages 301f and 301g, the divisions are quarters of a unit; this diagram can be used for larger dimensions than the other, but the results cannot be read so accurately, $\frac{1}{4}$ inch being the limit for direct readings and $\frac{1}{16}$ inch, by estimation, when the unit is an inch as before. In the lower diagram on pages 301j and 301k, the divisions are twelfths of a unit and, therefore, this diagram is convenient for lengths in feet and inches: in the upper diagram on pages 301j and 301k, the divisions are tenths of a unit and the diagram is convenient for lengths in feet and decimals of a foot.

EXAMPLE 1.—If the legs of a right triangle are 18 inches and 14 inches, what is the hypotenuse?

SOLUTION.—This example may be readily solved by means of the diagram on pages 301f and 301g of *Smoley's Tables*, the units being called inches. Locate the vertical line for 18 in. and follow this line upwards until it intersects the horizontal line for 14 in. This point of intersection lies very nearly on the curved line that is one small division less than 23 in. Hence, the hypotenuse is approximately $22\frac{3}{4}$ in. Ans.

EXAMPLE 2.—If the hypotenuse of a right triangle is $9\frac{1}{4}$ inches and one leg is $6\frac{3}{8}$ inches, what is the other leg?

SOLUTION.—In this case, the diagram on pages 301b and 301c is most suitable, for, if the units are called inches, each small division represents $\frac{1}{8}$ in. Locate the horizontal line for $6\frac{3}{8}$ in., which is three divisions above the line marked 6. Then follow this line to the left until it intersects the curved line for $9\frac{1}{4}$ in., which is two divisions past the heavy curved line marked 9. The point of intersection is about midway between the first and second divisions to the right of the vertical line, marked $\frac{1}{2}$, that is between 6 and 7. Hence, the required leg is $6+\frac{1}{2}+\frac{1\frac{1}{2}}{8}=6\frac{11}{16}$ in. Ans.

It will be found that the vertical line for $6\frac{3}{8}$ in. does not intersect the curved line for $9\frac{1}{4}$ in. This means that the unknown leg is longer than

$6\frac{3}{8}$ in. and the horizontal line for $6\frac{3}{8}$ in. must be chosen to intersect the proper curved line.

EXAMPLE 3.—The legs of a right triangle are 10 feet 8 inches and 5 feet 4 inches; find the hypotenuse.

SOLUTION.—Since the dimensions are in feet and inches, the lower diagram on pages 301j and 301k may be used. First locate the vertical line representing 10 ft. 8 in., which is two small divisions to the right of the line marked 6″ between 10′ and 11′. Then follow this line upwards until it intersects the horizontal line corresponding to 5 ft. 4 in., which is one division higher than the first heavy line above 5′. This point of intersection lies on the curved line that is one division less than 12′. The hypotenuse is therefore about 11 ft. 11 in. Ans.

EXAMPLES FOR PRACTICE

1. The hypotenuse of a right triangle is $23\frac{3}{4}$ inches and one leg is 20 inches. Find the other leg by the diagram in *Smoley's Tables*.

Ans. $12\frac{3}{4}$ in.

2. The two legs of a right triangle are 9 feet 7 inches and 7 feet 3 inches. Find the hypotenuse by means of the diagram in *Smoley's Tables*.

Ans. 12 ft.

SOLUTION OF OBLIQUE TRIANGLES

38. Kinds of Problems.—In solving an oblique triangle in structural work, it is simpler in many cases to divide the given triangle into two right triangles by dropping a perpendicular from a vertex to the opposite side, and then to solve each right triangle by the aid of the Parallel Tables and Tables of Bevels.

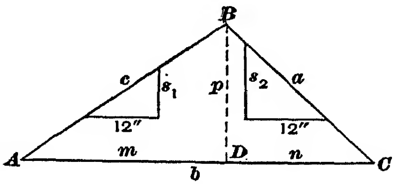

FIG. 13

Problems in oblique triangles in structural work may be divided into four groups: (1) Given the three sides; to find the bevels of two of them with respect to the third. Usually, it is also required to find the distances m and n, Fig. 13, intercepted by the perpendicular from B to AC. (2) Given two sides and the logarithmic functions of the angle between them; to find the length and bevel of the third side. (3)

Given one side and the bevels of the other two sides with respect to the first; to find the lengths of the other sides. (4) Given two sides and the bevel of the third side; to find the bevel of one known side and the length of the unknown side. Nearly all practical problems in structural work are in one or the other of the first two classes, but for completeness all the cases will be treated here.

39. Case I.—*Given three sides.* Let the sides a, b, and c, Fig. 13, be known and let it be required to find the distances m and n and the bevels s_1 and s_2. Formulas for determining m and n are derived as follows: In the right triangle ABD, $m = c \cos A$; and in the right triangle CBD, $n = a \cos C$. But, from trigonometry, $\cos A = \dfrac{b^2+c^2-a^2}{2\,b\,c}$ and $\cos C = \dfrac{a^2+b^2-c^2}{2\,ab}$.

Hence, by substitution,

$$m = \frac{b^2+c^2-a^2}{2\,b} \qquad (1)$$

and

$$n = \frac{a^2+b^2-c^2}{2\,b} \qquad (2)$$

As a check, $m+n=b$

Next, in the right triangle $A\,B\,D$, $\sec A = \dfrac{c}{m}$, whence

$$\log \sec A = \log c - \log m$$

Similarly, in the triangle $C\,B\,D$,

$$\log \sec C = \log a - \log n$$

The bevels s_1 and s_2 corresponding to these values of log sec A and log sec C, respectively, may then be found from the Tables of Bevels.

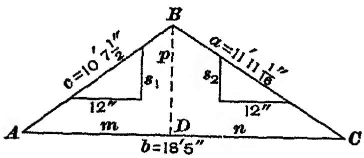

Fig. 14

EXAMPLE.—In Fig. 14, c, a, and b are, respectively, 10 feet $7\frac{1}{2}$ inches, 11 feet $11\frac{1}{16}$ inches, and 18 feet 5 inches. Find m, n, s_1, and s_2.

SOLUTION.—By formulas 1 and 2, $m = \dfrac{b^2+c^2-a^2}{2\,b}$ and $n = \dfrac{a^2+b^2-c^2}{2\,b}$. The values of a^2, b^2, and c^2 may be taken directly from the Parallel Tables. The numerical value of each numerator is then found and its

logarithm taken from the Tables of Common Logarithms of Numbers. The values of log a, log b, and log c are taken from the Parallel Tables at the same time that a^2, b^2, and c^2 are found because log a and log c are required in finding log sec A and log sec C and, consequently, s_1 and s_2. From the logarithm of each numerator, log 2 b is subtracted to give log m and log n; and then m and n are found from the Parallel Tables. The work may be arranged as follows:

$$\begin{array}{rl} b^2 = & 339.1736 \\ c^2 = & \underline{112.8906} \\ b^2+c^2 = & 452.0642 \\ a^2 = & \underline{142.1311} \\ b^2+c^2-a^2 = & 309.9331 \\ \log(b^2+c^2-a^2) = & 2.49126 \\ \log 2b = & \underline{1.56624} \\ \log m = & 0.92502 \end{array} \qquad \begin{array}{rl} \log b = & 1.26521 \\ \log 2 = & \underline{0.30103} \\ \log 2b = & 1.56624 \end{array}$$

$m = 8$ ft. $4\frac{31}{32}$ in. Ans.

$$\begin{array}{rl} a^2 = & 142.1311 \\ b^2 = & \underline{339.1736} \\ a^2+b^2 = & 481.3047 \\ c^2 = & \underline{112.8906} \\ a^2+b^2-c^2 = & 368.4141 \\ \log(a^2+b^2-c^2) = & 2.56633 \\ \log 2b = & \underline{1.56624} \\ \log n = & 1.00009 \end{array}$$

$n = 10$ ft. $\frac{1}{32}$ in. Ans.

As a check, $m+n=b$ or 8 ft. $4\frac{31}{32}$ in. + 10 ft. $\frac{1}{32}$ in. = 18 ft. 5 in.

Next, log sec A = log c − log m and log sec C = log a − log n. Then the bevels s_1 and s_2 are found from the Tables of Bevels.

$$\begin{array}{rl} \log c = & 1.02633 \\ \log m = & \underline{0.92502} \\ \log \sec A = & 0.10131 \end{array} \qquad \begin{array}{rl} \log a = & 1.07634 \\ \log n = & \underline{1.00009} \\ \log \sec C = & 0.07625 \end{array}$$

$s_1 = 9\frac{1}{4}$ in. Ans. $\qquad s_2 = 7\frac{25}{32}$ in. Ans.

40. Case II.—*Given two sides and the included angle.* Assume that the sides b and c, Fig. 13, and the angle A or its logarithmic functions are known; let it be required to find the side a and the bevel s_2. Usually, the logarithmic functions of the angle A are known from previous calculations, but sometimes the angle A itself or the bevel s_1 is given instead. Generally, it is also required to find the lengths m and n and, therefore, the following method is most convenient: First, find m and p by means of the relations $m = c \cos A$ and $p = c \sin A$, whence, log m = log c + log cos A and log p = log c + log

sin A. Then, since $n=b-m$, a and s_2 can be found from the right triangle BCD, in which the base and the altitude are known, by the formulas $a^2=p^2+n^2$ and $\log s_2=\log p-\log n$, as explained in Art. **30**.

EXAMPLE.—In Fig. 15, $c=11$ feet $6\frac{3}{8}$ inches, $b=17$ feet $7\frac{3}{4}$ inches, and $s_1=5\frac{1}{2}$ inches; find a and s_2.

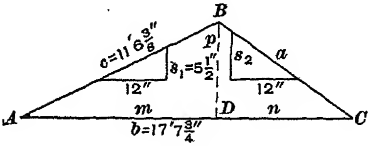

FIG. 15

SOLUTION.—First the right triangle ABD is solved for m and p by the relations $\log m=\log c+\log \cos A$ and $\log p=\log c+\log \sin A$. The values of log sin A and log cos A are taken from the Tables of Bevels and then m and p^2 are taken from the Parallel Tables corresponding to log m and log p. The work may be arranged as follows:

$$\log m=1.02047 \qquad m=10 \text{ ft. } 5\tfrac{25}{32} \text{ in.}$$
$$\log \cos A=9.95859$$
$$\log c=1.06188$$
$$\log \sin A=9.61978$$
$$\log p=0.68166 \qquad p^2=23.0850$$

After n is found by subtracting m from b, the right triangle BCD is solved for a and s_2 by the formulas $a^2=p^2+n^2$ and $\log s_2=\log \tan C=\log p-\log n$. The value of s_2 can be taken from either the Parallel Tables or the Tables of Bevels.

The calculations are arranged in the following manner:

$$n=17 \text{ ft. } 7\tfrac{3}{4} \text{ in.}-10 \text{ ft. } 5\tfrac{25}{32} \text{ in.}=7 \text{ ft. } 1\tfrac{31}{32} \text{ in.}$$

$$\log p=0.68166 \qquad p^2=23.0850$$
$$\log n=0.85516 \qquad n^2=51.3238$$
$$\log s_2=\log \tan C=9.82650 \qquad a^2=74.4088$$
$$s_2=8\tfrac{1}{16} \text{ in. Ans.} \qquad a=8 \text{ ft. } 7\tfrac{1}{2} \text{ in. Ans.}$$

If the angle A or one of its logarithmic functions is given instead of s_1, the method of solution is the same; but the values of log sin A and log cos A are taken from the Tables of Logarithmic Functions instead of the Tables of Bevels.

41. Case III.—*Given one side and the bevels of the other sides.* Suppose that the side b, Fig. 13, and the bevels s_1 and s_2 are given; and let it be required to find the sides a and c. First, it is convenient to determine the lengths m and n.

From the figure, $p=m \tan A$ and $p=n \tan C$; hence,

$$m \tan A=n \tan C$$

Since $n = b - m$, $m \tan A = (b - m) \tan C$, from which

$$m = \frac{b}{\tan A + \tan C} \times \tan C \qquad (1)$$

Similarly,

$$n = \frac{b}{\tan A + \tan C} \times \tan A \qquad (2)$$

Since s_1 and s_2 are known, the functions of the angles A and C can be readily found from the Tables of Bevels. Then, c and a are calculated from the relations $\log c = \log m + \log \sec A$ and $\log a = \log n + \log \sec C$.

EXAMPLE 1.—In Fig. 16, $b = 22$ feet $8\frac{1}{8}$ inches, $s_1 = 7\frac{1}{8}$ inches, and $s_2 = 8\frac{5}{16}$ inches; determine a and c.

SOLUTION.—First, m and n are computed by formulas **1** and **2**. Since $\log c$ and $\log a$ are afterwards determined from $\log m$ and $\log n$, it is not necessary to find m and n in feet and inches. To find $\log m$, subtract $\log (\tan A + \tan C)$ from $\log b$, and to the difference add $\log \tan C$. The value of $\log n$ is determined in a similar manner, but $\log \tan A$ is added instead of $\log \tan C$. From the Tables of Bevels corresponding to $s_1 = 7\frac{1}{8}$ in., $\tan A = .59375$ and $\log \tan A = 9.77360$; corresponding to $s_2 = 8\frac{5}{16}$ in., $\tan C = .69271$ and $\log \tan C = 9.84055$. Hence, $\tan A + \tan C = .59375 + .69271 = 1.28646$ and $\log (\tan A + \tan C) = 0.10940$.

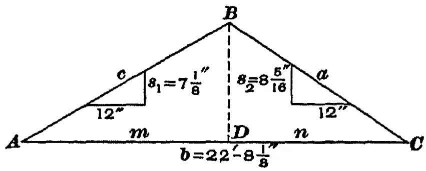

FIG. 16

The calculations for $\log m$ and $\log n$ are as follows:

$$\begin{aligned} \log b &= 1.35559 \\ \log (\tan A + \tan C) &= \underline{0.10940} \\ \text{difference} &= 1.24619 \\ \log \tan C &= \underline{9.84055} \\ \log m &= 1.08674 \end{aligned} \qquad \begin{aligned} &1.24619 \\ \log \tan A &= \underline{9.77360} \\ \log u &= 1.01979 \end{aligned}$$

The lengths of c and a are then computed by the relations $\log c = \log m + \log \sec A$ and $\log a = \log n + \log \sec C$. The values of $\log \sec A$ and $\log \sec C$ corresponding, respectively, to $s_1 = 7\frac{1}{8}$ in. and $s_2 = 8\frac{5}{16}$ in. are found in the Tables of Bevels; and c and a are taken from the Parallel Tables corresponding to their logarithms. The work is as follows:

$$\begin{aligned} \log m &= 1.08674 \\ \log \sec A &= \underline{0.06557} \\ \log c &= 1.15231 \end{aligned} \qquad \begin{aligned} \log n &= 1.01979 \\ \log \sec C &= \underline{0.08511} \\ \log a &= 1.10490 \end{aligned}$$

$c = 14$ ft. $2\frac{13}{32}$ in. Ans. $\qquad a = 12$ ft. $8\frac{25}{32}$ in. Ans.

EXAMPLE 2.—In Fig. 17, $b=14$ feet $6\frac{7}{8}$ inches, $s_1=3\frac{5}{8}$ inches, parallel, and $s_2=9\frac{1}{4}$ inches, perpendicular; find a and c.

SOLUTION.—The method of solving this problem is similar to that for example 1, but in this case the values of tan A and log tan A corresponding to a parallel level of $3\frac{5}{8}$ in. are found on pages 310 and 311 of the Tables of Bevels in the columns headed Cotang.; thus, tan $A=3.31034$ and log tan $A=0.51987$. The values of tan C and log tan C corresponding to a perpendicular bevel of $9\frac{1}{4}$ in. are, respectively, .77083 and 9.88696.

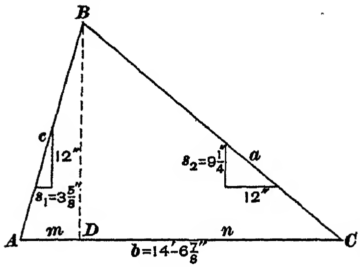

FIG. 17

Then, $\tan A+\tan C=3.31034+.77083=4.08117$, and $\log(\tan A+\tan C)=0.61079$.

The calculations for m and n follow:

$$\begin{array}{rl} \log b = & 1.16355 \\ \log(\tan A+\tan C) = & \underline{0.61079} \\ \text{difference} = & 0.55276 \\ \log \tan C = & \underline{9.88696} \\ \log m = & 0.43972 \end{array} \qquad \begin{array}{rl} & 0.55276 \\ \log \tan A = & \underline{0.51987} \\ \log n = & 1.07263 \end{array}$$

Finally, c and a are found by the relations $\log c=\log m+\log \sec A$ and $\log a=\log n+\log \sec C$. In this case, log sec A is found in the column on page 311 headed Cosec. The work may be arranged in the following manner:

$$\begin{array}{rl} \log m = & 0.43972 \\ \log \sec A = & \underline{0.53884} \\ \log c = & 0.97856 \\ c = & 9 \text{ ft. } 6\frac{7}{32} \text{ in.} \end{array} \qquad \begin{array}{rl} \log n = & 1.07263 \\ \log \sec C = & \underline{0.10127} \\ \log a = & 1.17390 \\ a = & 14 \text{ ft. } 11\frac{3}{32} \text{ in.} \end{array}$$

Ans.

42. Case IV.—*Given two sides and the bevel of the third side.* Let the sides c and b, Fig. 13, and the bevel s_2 be known; and let it be required to find the side a and the bevel s_1. The solution of this problem is similar to that for any oblique triangle in which two sides and the angle opposite one of them are given. First, the angle B is found by the formula $\sin B=\frac{b \sin C}{c}$, from which $\log \sin B=\log b+\log \sin C-\log c$.

Next, A is found by the relation $A=180°-B-C$. Then the value of s_1 corresponding to A is determined, and the value

of a is computed by the relation $a=\frac{c \sin A}{\sin C}$, from which $\log a = \log c + \log \sin A - \log \sin C$.

There are two angles, one acute and the other obtuse, which correspond to the value of $\sin B$ determined by the relation $\sin B=\frac{b \sin C}{c}$. One of the bevels is always known and it is usually possible to determine from the arrangement of the members forming the sides of the triangle whether the other bevel is a perpendicular bevel or a parallel one. The obtuse angle corresponding to $\sin B$ is taken when both bevels are perpendicular or, in case one is perpendicular and the other parallel, when the parallel bevel is greater numerically than the perpendicular bevel. The acute angle corresponding to $\sin B$ is taken when both bevels are parallel or, in case one is parallel and the other perpendicular, when the perpendicular bevel is greater numerically than the parallel bevel.

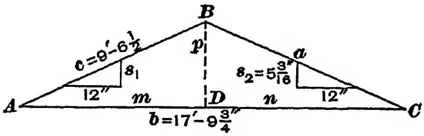

FIG. 18

EXAMPLE.—In Fig. 18, $b=17$ feet $9\frac{3}{4}$ inches, $c=9$ feet $6\frac{1}{2}$ inches, and $s_2=5\frac{3}{16}$ inches; find a and s_1.

SOLUTION.—First, apply the relation $\log \sin B = \log b + \log \sin C - \log c$; the value of $\log \sin C$ corresponding to $s_2=5\frac{3}{16}$ in. is taken from the Tables of Bevels. The obtuse angle corresponding to $\log \sin B$ is used because, as shown in Fig. 18, s_1 and s_2 are perpendicular bevels and, therefore, angles A and C are both less than 45°. The calculation for B is as follows:

$$\begin{aligned} \log b &= 1.25072 \\ \log \sin C &= \underline{9.59857} \\ \text{sum} &= 0.84929 \\ \log c &= \underline{0.97962} \\ \log \sin B &= 9.86967 \end{aligned}$$

$$B=180°-47°\ 47'\ 40''=132°\ 12'\ 20''$$

Then, $A=180°-B-C=180°-132°\ 12'\ 20''-23°\ 22'\ 40''=24°\ 25'$. The angle C corresponding to $s_2=5\frac{3}{16}$ in. is taken to the nearest 10 seconds from the Tables of Bevels. From the same tables, the bevel corresponding to angle A, or 24° 25′, is $s_1=5\frac{7}{16}$ in. Ans.

Lastly, a is computed from the relation $\log a = \log c + \log \sin A - \log \sin C$. In this case, $\log \sin A$ may be taken either from a table of logarithmic functions or from the Tables of Bevels; the former value is more accurate since the angle corresponding to the bevel $5\frac{7}{16}$ in. is 24° 22′ 35″, and therefore $\log \sin A$ is taken from a table of logarithmic functions for the angle 24° 25′.

The calculations are as follows:

$$\begin{aligned} \log c &= 0.97962 \\ \log \sin A &= \underline{9.61634} \\ \text{sum} &= 0.59596 \\ \log \sin C &= \underline{9.59857} \\ \log a &= 0.99739 \end{aligned}$$

$a = 9$ ft. $11\frac{9}{32}$ in. Ans.

EXAMPLES FOR PRACTICE

1. In Fig. 13, $c = 8$ feet $6\frac{1}{2}$ inches, $a = 10$ feet $7\frac{1}{4}$ inches, and $b = 15$ feet 3 inches. Find the distances m and n and the bevels s_1 and s_2.

Ans. $\begin{cases} m = 6 \text{ ft. } 3\frac{31}{32} \text{ in.}; \; n = 8 \text{ ft. } 11\frac{1}{32} \text{ in.} \\ s_1 = 10\frac{7}{8} \text{ in.}; \; s_2 = 7\frac{23}{32} \text{ in.} \end{cases}$

2. If c, Fig. 13, is 13 feet $6\frac{1}{4}$ inches, b is 21 feet 7 inches, and s_1 is $4\frac{5}{8}$ inches, find a and s_2.

Ans. $\begin{cases} a = 10 \text{ ft. } 2\frac{13}{32} \text{ in.} \\ s_2 = 6\frac{1}{2} \text{ in.} \end{cases}$

3. In Fig. 13, $b = 18$ feet $3\frac{7}{8}$ inches, $s_1 = 5\frac{3}{16}$ inches, and $s_2 = 7\frac{1}{2}$ inches; find a and c.

Ans. $\begin{cases} a = 8 \text{ ft. } 10\frac{1}{32} \text{ in.} \\ c = 11 \text{ ft. } 9\frac{19}{32} \text{ in.} \end{cases}$

4. In Fig. 13, $a = 14$ feet 1 inch, $b = 24$ feet $8\frac{1}{4}$ inches, and $s_1 = 6\frac{1}{4}$ inches; find c and s_2.

Ans. $\begin{cases} c = 13 \text{ ft. } 7\frac{19}{32} \text{ in.} \\ s_2 = 6 \text{ in.} \end{cases}$

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43. Solution of Frame.—The application of the methods* explained in the preceding articles to the solution of a frame is shown in the following example.

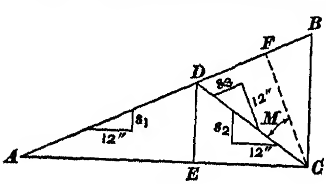


FIG. 19

EXAMPLE.—In Fig. 19, $AC = 14$ feet 4 inches, $BC = 6$ feet 2 inches, and $AE = 8$ feet $10\frac{1}{2}$ inches. Find the lengths and bevels of the members of the frame.

*Additional applications may be found in *Smoley's Tables*, pages 346 to 349.

SOLUTION.—In the right triangle BAC, the base and the altitude are known and the length and bevel of the hypotenuse, as well as the logarithmic functions of the angle A, may be calculated in the manner explained in Art. **30**. The calculations are as follows:

$$\begin{array}{rlrl} \log BC &= 0.79005 & \overline{BC}^2 &= 38.0278 \\ \log AC &= \underline{1.15635} & \overline{AC}^2 &= \underline{205.4444} \\ \log \tan A = \log s_1 &= 9.63370 & \overline{AB}^2 &= 243.4722 \end{array}$$

From the Parallel Tables, $AB = 15$ ft. $7\frac{1}{4}$ in., $\log AB = 1.19324$, $s_1 = 5\frac{5}{32}$ in., and $s_1^2 = .1846$.

As a check, $\log \sec A = \log AB - \log AC = 1.19324 - 1.15635 = 0.03689$, and the corresponding number in the Parallel Tables is 1 ft. $1\frac{1}{16}$ in. Also, $\sec^2 A = 1^2 + s_1^2 = 1 + .1846 = 1.1846$, which is the square of the same number, 1 ft. $1\frac{1}{16}$ in. The work is, therefore, correct.

Next, in the right triangle ADE, the base AE and the logarithmic tangent and secant of the angle A are known; hence, DE and AD can be determined by the formulas $\log DE = \log AE + \log \tan A$ and $\log AD = \log AE + \log \sec A$. The work may be arranged in the following manner:

$$\begin{array}{rll} \log DE &= \underline{0.58187} & DE = 3 \text{ ft. } 9\frac{13}{16} \text{ in.} \\ \log \tan A &= 9.63370 & \\ \log AE &= 0.94817 & \\ \log \sec A &= \underline{0.03689} & \\ \log AD &= 0.98506 & AD = 9 \text{ ft. } 7\frac{15}{16} \text{ in.} \end{array}$$

As a check,

$$\begin{array}{rll} \overline{DE}^2 &= 14.5749 & \\ \overline{AE}^2 &= \underline{78.7656} & \\ \overline{AD}^2 &= 93.3405 & AD = 9 \text{ ft. } 7\frac{15}{16} \text{ in.} \end{array}$$

Then, in the right triangle CDE, the altitude DE is known and the base $EC = AC - AE = 14$ ft. 4 in. $-$ 8 ft. $10\frac{1}{2}$ in. $=$ 5 ft. $5\frac{1}{2}$ in.; therefore, CD and the bevel s_2 may be found by the formulas $\overline{CD}^2 = \overline{DE}^2 + \overline{EC}^2$ and $\log s_2 = \log DE - \log EC$. The work follows:

$$\begin{array}{rlrl} \log DE &= 0.58187 & \overline{DE}^2 &= 14.5749 \\ \log EC &= \underline{0.73706} & \overline{EC}^2 &= \underline{29.7934} \\ \log s_2 &= 9.84481 & \overline{CD}^2 &= 44.3683 \end{array}$$

From the Parallel Tables, $CD = 6$ ft. $7\frac{15}{16}$ in., $\log CD = 0.82357$, $s_2 = 8\frac{13}{32}$ in., and $s_2^2 = .4907$. As a check, $\log \sec C = \log CD - \log EC = 0.82357 - 0.73706 = 0.08651$; this is the logarithm of 1 ft. $2\frac{21}{32}$ in. Also, $\sec^2 C = 1^2 + s_2^2 = 1 + .4907 = 1.4907$; this is the square of the same number, 1 ft. $2\frac{21}{32}$ in. The work is, therefore, correct.

In laying out the joint at D, the bevel of DC with respect to AB is required. The bevel s_3 can be found in three ways, any one of which may be used. In one method the oblique triangle BCD is solved; its three sides

are known, since BC is given, CD has just been computed, and $BD=AB-AD=15$ ft. $7\frac{1}{4}$ in. -9 ft. $7\frac{15}{16}$ in. $=5$ ft. $11\frac{5}{16}$ in. Then,

$$\cos D=\frac{\overline{CD}^2+\overline{BD}^2-\overline{BC}^2}{2\,CD\times BD}$$

The calculations for cos D follow:

$$\begin{aligned}\overline{CD}^2&=44.3683\\ \overline{BD}^2&=\underline{35.3158}\\ \text{sum}&=79.6841\\ \overline{BC}^2&=\underline{38.0278}\\ \text{difference}&=41.6563\end{aligned}\qquad\qquad \begin{aligned}\log CD&=0.82357\\ \log BD&=0.77398\\ \log 2&=\underline{0.30103}\\ \text{sum}&=1.89858\end{aligned}$$

$$\begin{aligned}\log(\overline{CD}^2+\overline{BD}^2-\overline{BC}^2)&=1.61968\\ \log(2\,CD\times BD)&=\underline{1.89858}\\ \log\cos D&=9.72110\end{aligned}$$

Since log cos D is less than 9.84949, the angle D is greater than 45°; hence, the bevel s_3 is the tangent of the complementary angle M, constructed by drawing CF perpendicular to AB. The required bevel is then found from the Tables of Bevels corresponding to a logarithmic sine equal to 9.72110, and its value is $s_3=7\frac{7}{16}$ in.

In the second method of finding s_3, the right triangle ACF is solved first. The hypotenuse AC is known and the logarithmic functions of angle A may be determined from the values derived in the solution of the triangle BAC; then, CF and AF are found by the relations $\log CF=\log AC+\log\sin A$ and $\log AF=\log AC+\log\cos A$. Since $DF=AF-AD$, bevel s_3 can be found from the relation $s_3=\frac{DF}{CF}$, whence $\log s_3=\log DF-\log CF$. The calculations are as follows:

$$\log\sin A=\log BC-\log AB=0.79005-1.19324=9.59681$$
$$\log\cos A=\log AC-\log AB=1.15635-1.19324=9.96311$$

and

$$\begin{aligned}\log CF&=\underline{0.75316}\\ \log\sin A&=9.59681\\ \log AC&=1.15635\\ \log\cos A&=\underline{9.96311}\\ \log AF&=1.11946\quad AF=13\text{ ft. }2\text{ in.}\end{aligned}$$

Then, $DF=AF-AD=13$ ft. 2 in. -9 ft. $7\frac{15}{16}$ in. $=3$ ft. $6\frac{1}{16}$ in.

$$\begin{aligned}\log DF&=0.54471\\ \log CF&=\underline{0.75316}\\ \log s_3&=9.79155\quad s_3=7\tfrac{7}{16}\text{ in.}\end{aligned}$$

The third method of determining s_3 makes use of the relation that angle BDC is equal to the sum of angles DAE and DCE, since BDC is an exterior angle of the oblique triangle ADC. The angles DAE and DCE are found from the Tables of Bevels corresponding to s_1 and s_2, respectively. Thus,

on page 315, it is found that, for the bevel $s_1 = 5\frac{5}{32}$ in., the angle $DAE = 23°\ 15'\ 9''$ and from page 321, for the bevel $s_2 = 8\frac{13}{32}$ in., the angle $DCE = 35°\ 0'\ 43''$. Hence, angle $BDC = 23°\ 15'\ 9'' + 35°\ 0'\ 43'' = 58°\ 15'\ 52''$. Since the angle is greater than 45°, the bevel is determined from the complementary angle, which equals $90° - 58°\ 15'\ 52'' = 31°\ 44'\ 8''$. By this method also, it is found from page 319 that s_3 is $7\frac{7}{16}$ in.

EXAMPLE FOR PRACTICE

In Fig. 19, $BC = 5$ feet $10\frac{1}{2}$ inches, $AC = 15$ feet $7\frac{1}{4}$ inches, and $AE = 9$ feet 1 inch; find the lengths and bevels of the members of the frame.

$$\text{Ans.}\begin{cases} s_1 = 4\frac{17}{32} \text{ in.} \\ AD = 9 \text{ ft. } 8\frac{15}{32} \text{ in.} \\ DE = 3 \text{ ft. } 5\frac{1}{32} \text{ in.} \\ s_2 = 6\frac{9}{32} \text{ in.} \\ CD = 7 \text{ ft. } 4\frac{11}{32} \text{ in.} \\ BD = 6 \text{ ft. } 11\frac{5}{8} \text{ in.} \\ s_3 = 10\frac{11}{16} \text{ in.} \end{cases}$$

ELEMENTS OF STRUCTURAL DRAWING

(PART 1)

INTRODUCTION

PRELIMINARY CONSIDERATIONS

CLASSIFICATION OF STRUCTURAL DRAWINGS

1. Structural Drawing.—The fundamental principles on which all mechanical drawing is based were explained and applied in *Geometrical Drawing*. In structural drawing these principles are employed to represent graphically the appearance, structural features, and dimensions of proposed structures or their component parts. Thus, an entire bridge, or only one of the members of which it is composed, may be drawn. Structural drawings are usually classified according to their scope and purpose into design drawings and detail drawings.

2. Design Drawings.—A design drawing shows the general appearance and size of the structure—such as bridge, trestle, office, or mill building—and gives the arrangement, composition, and principal dimensions of its main members. Whatever details are shown on it are of a general nature and they serve to illustrate more clearly the main structural features. Design drawings are intended for use in making esti-

mates of the cost of the structure, and in preparing the detail drawings.

3. Detail Drawings.—A detail drawing shows the exact shape and size of one or more parts of the structure and gives all dimensions and information necessary for their construction, making proper provisions for their connections to the other members of the structure. Detail drawings are intended for use by the workmen in the shop or field, and must, therefore, be sufficiently plain and explicit to be read easily by men whose knowledge of drawing is limited. They must also contain all the information necessary to carry out the work without further explanations by the draftsman.

PENCIL DRAWINGS, TRACINGS, AND BLUEPRINTS

4. Pencil Drawings.—In many drafting rooms it is customary to make all structural drawings first in pencil on paper. Usually, these drawings are not inked in. Any good grade of Manila paper on which lines can be easily drawn and erased may be used. A 6-H or 4-H pencil is well adapted to this kind of work, the harder 6-H being more suitable for fine lines and the 4-H for heavier lines. A 3-H pencil is generally preferred for lettering on paper drawings. These drawings are called *original,* or *pencil, drawings*; they are seldom kept for permanent records after tracings of them have been completed.

5. Tracings.—When the pencil drawings are finished, they are reproduced by tracing the lines on specially prepared cloth, called *tracing cloth.* Tracing cloth is linen treated with a waxy sizing so as to make it semitransparent. After the tracing cloth is sized, one side is dull and slightly rough, and the other is bright and smooth, presenting a glazed surface.

In copying a drawing on tracing cloth, the cloth is tacked over the drawing, and the lines on the cloth are drawn by following those on the drawing, which are plainly seen through the cloth. A drawing thus copied on tracing cloth is called a *tracing.* Tracings can also be made on tracing paper, which is

transparent paper especially prepared for this purpose. When, however, a tracing is to have much handling, cloth is preferable to paper.

It is the accepted practice in many drafting rooms to make all drawings in pencil directly on tracing cloth or tracing paper. A 3-H or 2-H pencil is most suitable for such purposes. The pencil work is then usually inked in. In some drafting rooms inking is entirely omitted and the tracings are left in pencil. The pencil lines on such tracings should be drawn with that end in view and should be made sufficiently clear and heavy. There are several types of tracing cloth on the market which are specially adapted to such work. The main advantages of leaving tracings in pencil are that the time spent in inking is saved and that changes may be more easily made, pencil lines being easier to erase than ink lines. The serious disadvantages to such practice are that the blueprints made of pencil tracings are never so clear as those made of inked tracings, and that pencil tracings never possess the degree of permanence possessed by inked tracings, the pencil lines smearing very readily.

6. Blueprints.—When tracings are finished, as many copies of them as are desired may be obtained by a special process called *blueprinting*. These copies, called blueprints are taken on blueprint paper, which is a white paper coated on one side with a chemical preparation that is sensitive to light and gives the paper a yellowish-green color. Unless previously exposed to light, the coating may be entirely removed by immersing the paper in water. When exposed to sunlight, bright daylight, or brilliant artificial light, the coating undergoes a chemical change that colors the surface of the paper blue, which color cannot be removed by washing. The process of blueprinting is based on this principle.

In making a blueprint the tracing is put on a sheet of blueprint paper—the coated surface of the paper and the pencil or ink lines of the tracing being uppermost—and the two, held in close contact by a plate of glass placed over them, are exposed to the brightest available light, for as long a period as the

sensitiveness of the paper may require. The tracing being semitransparent except where inked or penciled, the exposure to light produces the described color change in all parts of the coating of the paper that are not directly under the inked or penciled lines. The paper is then removed, immersed in clear water, and thoroughly washed; this process removes the coating from all parts that were covered by the ink lines, leaving them white, while the remainder of the paper stays colored. The result is an exact reproduction of the tracing in white lines on a blue ground. As many prints as are desired can be made, one at a time, from the same tracing.

DRAFTING-ROOM ORGANIZATION

7. Drafting Room.—The various drawings and estimates are made in the drafting room. The number of men in the drafting room and their organization vary with the size and needs of the concern of which the drafting room is a part. Thus, the personnel may range from one individual for a small establishment to a large and highly specialized organization for a large steel plant. The drafting room of a steel company of average size consists of two departments: the *designing and estimating department*, and the *detailing department*. Both are under the supervision of the chief engineer. In smaller steel companies the two departments are combined in one Many construction companies, other than steel companies, have only a designing department and let the work of the detailing department be carried out by the company that supplies the steel work.

8. Chief Engineer.—The chief engineer is the responsible head of the entire engineering organization. It is his duty to see that the departments under his supervision cooperate properly and work efficiently. He decides all important questions that come up in the engineering organization. Therefore, he should be a farsighted executive of excellent engineering training and wide experience as an engineer, and one who is able to produce results by virtue of his ability to lead men. He is

usually assisted by one or more immediate subordinates, one of whom takes charge of the designing department.

9. Designing Department.—In the designing department are made all preliminary sketches, estimates of cost, and design drawings for proposed structures. Besides its immediate head, this department is composed of a staff of designers, estimators, draftsmen, and checkers.

10. Designers.—The designers make all the necessary computations and sketches for the design drawings. Sometimes they make these drawings themselves, but more often leave that to the draftsmen who work from the prepared sketches under the supervision of the designers. The designs are made so that the structures will safely withstand all loads coming on them with the least expenditure for materials and labor. Safety and economy are, therefore, the guides to proper designs.

11. Estimators.—The estimators make careful estimates of the quantities of materials to be used in the proposed structure, determine the proper unit costs of the materials, and compute the probable cost of the structure. Both the designers and the estimators must be well versed in the principles of engineering that govern the design of the type of construction in which they are engaged; they must be thoroughly familiar with best designing practice and the methods of making detail drawings; they must also be able to make economic designs and to compute accurately. Most designers and estimators are men who were once engaged in making detail drawings, and often also in supervising construction; they, therefore, possess a good knowledge of shop and construction methods.

12. The correctness of the designs or estimates are frequently verified by a more experienced designer or estimator. In nearly all cases the designs and estimates are finally inspected by the chief engineer or his immediate subordinates. In the smaller drafting rooms there is no such clearly defined division of tasks as just described, and each man may be called on to perform various kinds of work at different times.

13. Detailing Department.—When the design is finally completed, approved by the chief engineer, and accepted by the customer for whom the structure is to be built, the design drawings are sent to the detailing department to be used for making detail drawings. In the detailing department are made all the detail drawings required by the workmen in the shop or on construction, and also the bills of materials necessary for ordering in advance the materials for the structure from the mills and the shop bills for gathering the proper materials together in the shop.

14. Chief Draftsman.—The detailing department is under the supervision of the chief draftsman, who is responsible to the chief engineer or his immediate subordinates for the efficiency of his department. It is his duty to see that the work of his department is properly carried out, that the different tasks are assigned to those most capable of performing them, and that proper cooperation exists among the various groups of employes under his charge. He must, therefore, be a man of wide experience in structural drawing, well acquainted with shop and construction methods, and an able executive of agreeable personality.

15. Squads.—To facilitate their administration, the larger detailing departments are divided into squads. Each squad is under the direction of a squad boss, or leader, and is composed of one or more checkers, and of several detailers and tracers.

16. Squad Boss.—The squad boss is usually more experienced than the other men of his squad. He receives the work for the squad from the chief draftsman and apportions it among his subordinates according to their abilities. Frequently, he also does checking and detailing. He generally decides the important detailing questions in the squad and keeps a record of the progress of the work.

17. Detailers.—The detail draftsman, or detailer, prepares the detail drawings from the design drawings, computing all dimensions from the information furnished on the latter,

and often makes the bills for ordering materials. He should have a good knowledge of structural drawing, some training in engineering principles, and a familiarity with the standard details of the types of construction in which he is engaged. He must be able to make neat drawings and to compute dimensions accurately. A knowledge of shop and construction methods is an invaluable asset to him. The detailer usually makes his drawings in pencil either on paper or tracing cloth; sometimes, he also does the tracing or inking himself, but more frequently leaves that to be done by the less experienced tracers.

18. Tracers.—The tracer usually makes tracings of the drawings prepared by the detailer, or draws simple detail drawings from sketches furnished to him. He must be familiar with the use of instruments, be able to make neat and careful tracings, and do fairly good lettering, the appearance of the tracing depending entirely upon his skill. In this position he has a good opportunity of acquainting himself with the methods of making detail drawings. Some knowledge of engineering principles and a familiarity with standard details will invariably hasten his promotion to the position of detailer.

19. Checkers.—The completed tracings are turned over to the checker, who examines the drawings carefully to make sure that the details are of the most suitable type and verifies the correctness of all dimensions given and notes made. Whatever additions or changes he recommends, he marks in pencil either on the tracing, or preferably on a blueprint of it, and turns it over to the detailer for verification and correction. After the drawing is corrected and completely rechecked, the checker assumes entire responsibility for its correctness. His position is, therefore, quite responsible and he should be a thoroughly accurate man of considerable experience as detailer. He should also be well acquainted with shop and construction methods. Some familiarity with the methods of design is a great help to him.

20. Filing System.—The tracings are kept in a fireproof vault where they are filed according to a definite system, so that they may be found without much difficulty. The task of

on one edge into tenths of an inch, on the opposite edge int fiftieths of an inch, and on the remaining edges into twentieths thirtieths, fortieths, and sixtieths of an inch, as indicated b markings at the centers of the respective edges.

On the edge marked *10* at the center, every inch is indicate by a figure and is divided into 10 divisions. If in drawing map the scale of 1 inch=10 feet is used, each division wil represent $\frac{1}{10}$ of 10 feet, or 1 foot, 10 divisions will represen 10 feet, 20 divisions will represent 20 feet, etc. If the divi- sion line marked *0* is placed at the beginning of a line to b measured, the division line marked *2* will indicate 20 feet t the given scale, the division line marked *3* will indicate 30 feet etc.

On the edge marked *50* at the center, each inch is divided into 5 divisions which are subdivided into 10 subdivisions, each subdivision being $\frac{1}{50}$ inch. Every alternate division on the scale is marked with a number *2, 4, 6, 8, 10,* etc. If a scale of 1 inch=50 feet is to be used, then each division of the scale will represent 10 feet, and each subdivision will represent 1 foot.

The engineer's scale is of particular advantage in drawing diagrams, known as *stress diagrams,* in which forces are repre- sented graphically. For instance, when a stress diagram is to be drawn to such a scale that 1 inch represents 6,000 pounds, or 1″=6,000 lb., the scale marked 60 at the center is gener- ally used; each smallest division on that scale then represents $\frac{1}{60}$ of 6,000 pounds, or 100 pounds. If it is desired to draw a stress diagram to a scale of 1′=500 lb., the scale marked *50* at the center is used, each smallest division representing 10 pounds. The use of the inch rule, as usually divided into eighths and sixteenths, for such work would be attended with considerable inconvenience. For example, if it were desired to lay off 5,500 pounds when the scale of the diagram is 6,000 pounds per inch, it would be necessary to divide 5,500 by 6,000 and thus obtain the result $\frac{11}{12}$ inch, which would be diffi- cult to measure with any degree of accuracy.

LETTERING

28. Importance of Clearness in Lettering.—Too muc stress cannot be laid on the importance of learning how t letter neatly. The appearance and clearness of a drawin depends to a large extent on the neatness and legibility of th lettering on it. On all structural drawings there are nume ous notes describing the structural features shown, and it essential that these notes be lettered clearly so as to avoid pos sible confusion. It is still more important to make all dimer sion figures distinct and legible, because the mistaking of dimension figure may lead to serious losses in time and mone

29. Single-Stroke Lettering.—On account of its legibilit and the rapidity with which it can be executed, single-strok

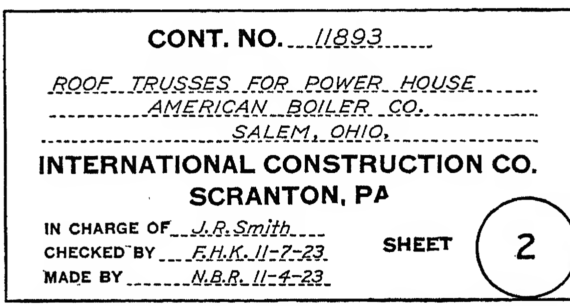


FIG. 3

lettering has become standard in nearly all structural draftin rooms in this country. Both the slant and vertical styles ar in use, but the former is more extensively used than the latte because of the greater ease with which its strokes may be made

Single-stroke slant lettering only will be used on the draw ing plates of this Section. Unless the beginner has alread acquired a fair degree of skill in this style of lettering, he i advised to practice it during his spare moments, because onl through continuous efforts to improve his style can he becom a good letterer.

30. Stamps.—There are many devices that may b adopted in order to save time in lettering a drawing. Fo

instance, where there is much descriptive matter on the drawing, one may place under the tracing cloth on which the drawing is made, a sheet of ruled cross-section paper and use the rulings as guide lines for the lettering. It is customary in many drafting rooms to print that part of the title and the information that is common to all drawings with a rubber stamp or a printing machine. A typical illustration of a title printed in part with a printing machine is shown in Fig. 3.

LINES

31. Thickness of Lines.—In Fig. 4 are shown the different conventional lines generally used on structural drawings. These lines are usually made of three different widths or thicknesses. The lines shown in (*a*) and (*b*) are drawn very fine, and just sufficiently heavy on the paper drawing to show through the tracing cloth, and on the tracing to print clearly on the blueprint. They should be of even width throughout the drawing. The lines shown in (*c*), (*d*), (*e*),

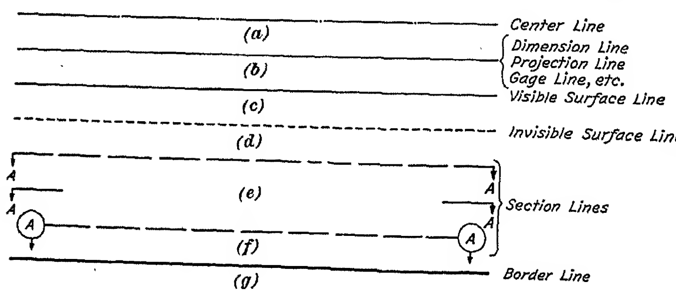


Fig. 4

and (*f*) are drawn sufficiently heavy to contrast clearly with the finer lines. There is no fixed rule for the width of these lines. The heavier they are drawn, the more distinctly they show on the blueprint. However, the heavier inked lines on tracings take more time to dry and are harder to erase. The border line shown in (*g*) is usually the heaviest line on a drawing. It should be made with one stroke of the pen, and should not exceed $\frac{1}{32}$ inch in width.

32. Surface Lines.—The visible surface lines shown in Fig. 4 (*c*) are used on drawings to represent the limits or outlines of visible surfaces. They are fairly heavy lines of even width. The invisible surface lines in (*d*) are used to represent outlines of surfaces hidden from view by intervening surfaces. They are fairly heavy dotted lines drawn with short dashes of even length which are spaced as closely as possible without running together. These lines show up best when drawn somewhat lighter than the visible surface lines. The length of the dashes may vary from $\frac{1}{16}$ inch to $\frac{3}{16}$ inch on different drawings, the shorter dashes being used on details of smaller scale and the longer on those of larger scale. The spacing and length of dashes are usually made by eye, and the draftsman soon acquires skill in making them uniform. Fig. 5 shows a perspective of a bent steel plate for one of the tools used in the erection of steelwork. A detail drawing of the steel plate is shown in Fig. 6. The outlines of the visible surfaces are represented by the heavy lines *a*, while the outlines of the hidden surfaces are represented by the somewhat lighter and dotted lines *b*.

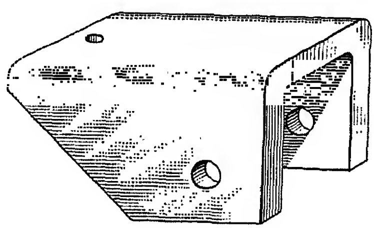


FIG. 5

33. Center Lines.—In laying out a drawing it is convenient in most cases to work from center lines. In construction it is also found practicable to work with these lines. Center lines are, therefore, important reference lines from which dimensions are frequently given. They are usually axes of symmetry of the object drawn, but often merely important lines in the object from which or along which dimensions are laid off. Many important dimensions are given between center lines. For instance, in most cases the spacing of columns, girders, or beams is given between center lines. Rivet or bolt holes are invariably located from center to center. Center lines are usually represented by light lines drawn with long dashes and dots alternating. In Fig. 6 the axes of symmetry

of the piece are indicated by the center lines *d*, the hole *g* is located by the center lines *d* and *f*, and the hole *h* by the center lines *e*. The center lines of bolt or rivet holes are usually drawn in full light lines in order to save time.

34. Dimension Lines.—Dimension lines are used to show the limits to which the dimensions apply. In most structural drafting rooms, dimensions are shown by continuous fine lines finished at both ends with arrowheads which are drawn free-hand and dimension figures that are placed immediately above the line and midway between the arrowheads, as in Fig. 6.

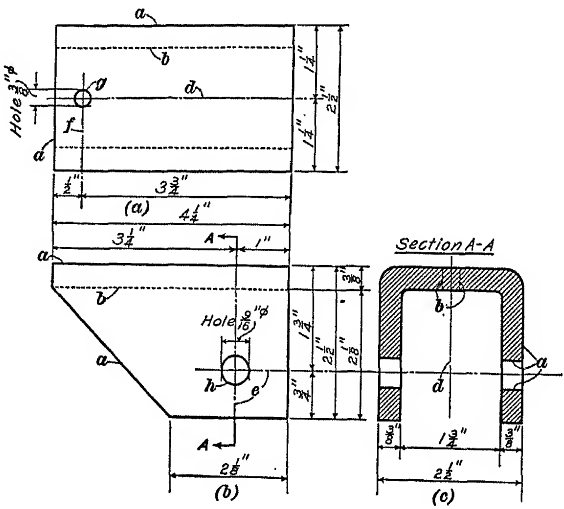


FIG. 6

This practice is different from that followed in mechanical drafting rooms, where the dimension lines are usually broken at the middle and the figures placed in the breaks. Experience has shown that the continuous line is more suited to structural drawings. In some structural drafting rooms it is customary to show dimension lines in fine dashed lines. The draftsman must follow the custom of the drafting room he is in.

For the sake of clearness, the dimension lines should be placed outside the views of the object drawn, unless it is found

distinctly advantageous to place them inside. They should be drawn parallel to the surfaces dimensioned and should touch the lines which limit them. Where the space between the lines limiting a dimension is narrow, the limits of the dimension are indicated by arrowheads placed outside the limiting lines and in contact with them. The dimension figure may then be written between these arrowheads, or elsewhere and pointed to the space to which it applies by an arrow. Correct and incorrect ways of showing dimensions are given in Fig. 7.

Where several dimension lines are used to dimension one view, sufficient space should be allowed between lines to avoid crowding of figures. The principal or over-all dimensions

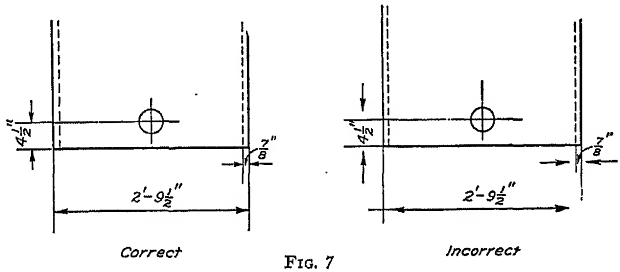


FIG. 7

should be placed farthest from the view, and the dimensions applying to only parts of the view nearest to it, as shown in Fig. 6. If avoidable, dimension lines should not be crossed. They should always be placed so that no doubt could possibly arise as to the limits of the dimensions. The dimensions form the backbone of the drawing and they should, therefore, be placed where they are most conspicuous. Dimension figures should be written distinctly and legibly, and made sufficiently large and heavy to stand out clearly on the drawing. In structural work the dimensions only are followed, the workmen being forbidden to scale drawings. A little judgment on the part of the draftsman will therefore save much of the time lost in the shop and field in hunting for dimensions.

SECTIONS AND SECTION LINING

35. Sections.—In order to present a clear conception of the object, or to show its interior construction, an imaginary section cut through it is often drawn in addition to the other views. Fig. 6 (*c*) shows a section taken along a plane through the vertical center lines of the holes *h*. The location of the section plane is indicated by lines, known as section lines, in one or more views of the object. The usual methods of drawing these section lines are shown in Fig. 4 (*e*) and (*f*), the arrowheads indicating the direction in which to look at the section. The section lines are usually distinguished by letters, capitals for large sections and lower-case for small sections, which are placed either at the ends of the arrowheads as in (*e*), or in circles as in (*f*). These letters should be made extra heavy so that the section may be easily located.

36. Section Lining.—When a section is taken through an object it is customary to indicate the materials of the different parts cut by certain combinations of lines, or section lining. Unfortunately, there is no universal system of section lining, and a certain combination of lines may denote cast iron in one office and brass in another. To avoid difficulty on account of this diversity of practice, the material should be distinctly specified on the drawing, unless there is no chance of error by the workmen as in the case of structural-steel drawings where only one material is used.

The most commonly used system of section lining is shown in Fig. 8, which is a reproduction of the Standard Sections recommended in the Manual of the American Railway Engineering Association, edition of 1921. Either one of the two standard sections shown for water may be used. When cut along the grain, wood is sectioned as in the upper of the two standard sections given, and when cut across the grain, as in the lower. In the section for brick, the courses may be omitted. Of the two sections shown for reinforced concrete, the broken-line symbol is employed when the reinforcement consists of rods or bars, and the zigzag symbol when it is of metal

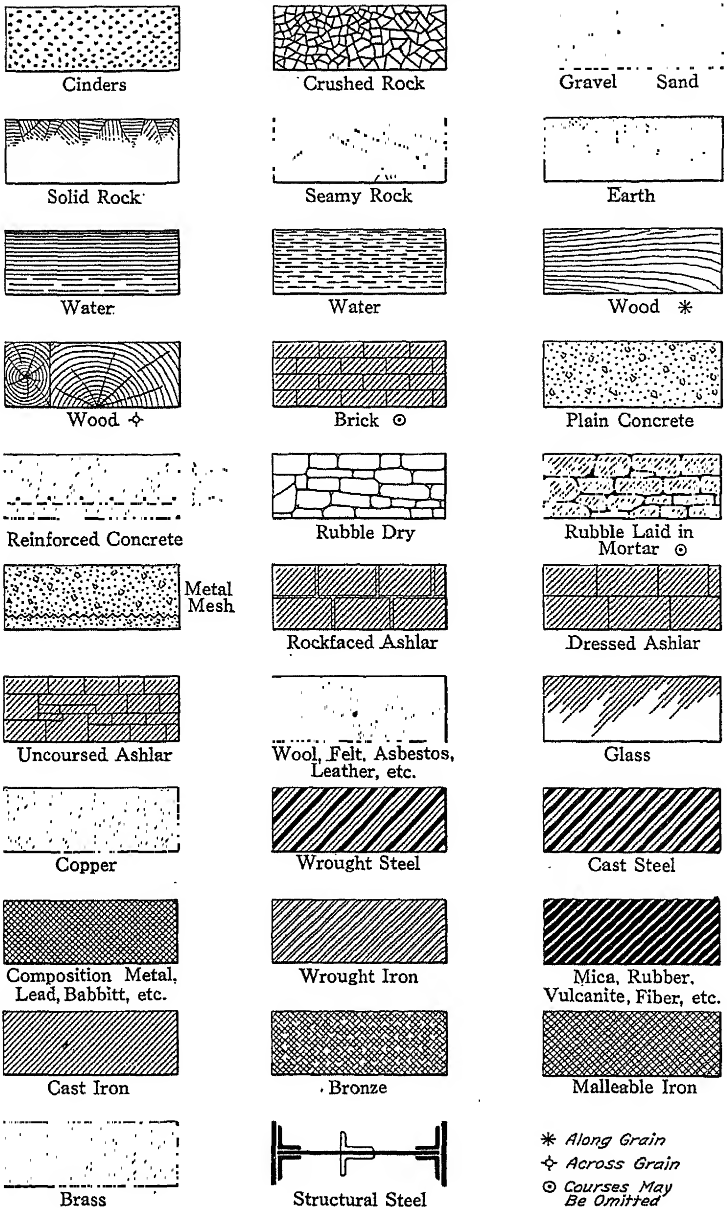

Cinders
Crushed Rock
Gravel
Sand
Solid Rock
Seamy Rock
Earth
Water
Water
Wood ✳
Wood ✧
Brick ⊙
Plain Concrete
Reinforced Concrete
Rubble Dry
Rubble Laid in Mortar ⊙
Metal Mesh
Rockfaced Ashlar
Dressed Ashlar
Uncoursed Ashlar
Wool, Felt, Asbestos, Leather, etc.
Glass
Copper
Wrought Steel
Cast Steel
Composition Metal, Lead, Babbitt, etc.
Wrought Iron
Mica, Rubber, Vulcanite, Fiber, etc.
Cast Iron
Bronze
Malleable Iron
Brass
Structural Steel
✳ Along Grain
✧ Across Grain
⊙ Courses May Be Omitted

FIG. 8

mesh. The sectioning for cast iron is frequently used for other materials in section, particularly on drawings where only

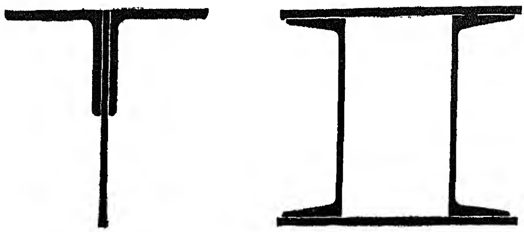


FIG. 9

one material is shown. In Europe, instead of representing sections by lines, colors are often used to indicate the different materials, but this practice is rarely followed in the United States.

37. Sectioning of Thin Materials.—When sections of material on a drawing appear too thin to be conveniently sectioned, or when it is desired to make the sections very prominent, they are blackened in, as shown in Fig. 9. In order to separate different pieces, a white line is usually left between them. Black sections are most frequently employed for sectional views of structures composed of plates and rolled sections such as **I** beams, angles, channels, rails, and **Z** bars. To save time, many structural draftsmen omit the section lining

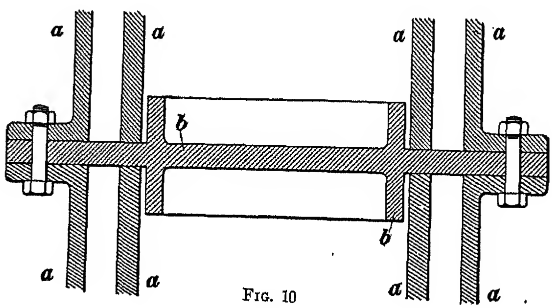


FIG. 10

in sections through thin materials, especially when the section can be easily interpreted without such section lining.

38. Representing Different Pieces of Section.—In drawing a sectional view of a member which consists of more than one piece, it is best to draw the section lining for the various pieces in different directions. It is the general rule that all parts of the same piece shown in section must be section-lined in the same direction. In Fig. 10 all parts marked *a* are of the same piece, and hence they are all sectioned in one direction, while the parts marked *b* are of another piece and are, therefore, sectioned at right angles to the section lining shown at *a*.

When the section cuts through a large number of pieces, it is not possible to draw the section lining of each piece in a direction different from those of the section lining of all the other pieces. This is illustrated in Fig. 11, which shows in (*a*) a section and in (*b*) an elevation of a bridge joint. The section shown in (*a*), taken along the plane *A A* in (*b*), cuts through many different pieces. In representing the various pieces, the section lining of all parts of the same piece are run in the same direction, and care is taken to draw the section lining in any two adjacent pieces in opposite directions, in order to distinguish one from another.

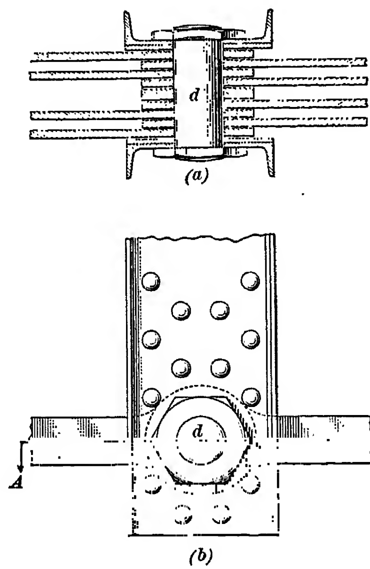


FIG. 11

39. Representing Curved Pieces in Section.—When the plane on which the section is taken passes through the axis of a bolt, pin, rivet, or other solid piece having a curved surface and connecting the parts of the member cut by the section, it is the general practice to show such curved piece in elevation and not in section. In Fig. 11 the section is taken along a

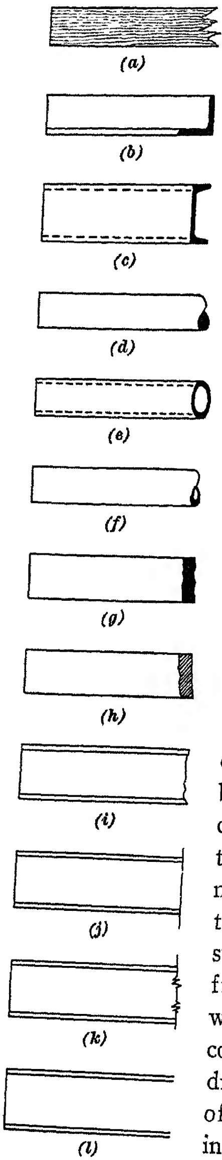


FIG. 12

plane that passes through the axis of the pin *d*. Nevertheless the pin is shown in the elevation and not in section, because this method of representation makes the drawing easier to read and saves the time spent in unnecessary section lining.

40. Breaks.—In drawing a long and slender object to a scale large enough to show all details clearly, the object often requires more space than is available; in this case part of the object is broken out and the ends are pushed together. The fact that a portion of the object was omitted for the sake of convenience is indicated by a so-called *break*. Conventional methods of indicating breaks are shown in Fig. 12. In wooden members, breaks are conveniently indicated as in (*a*); in structural-steel shapes, as in (*b*) and (*c*); and in cylindrical objects, as in (*d*). Breaks in hollow cylindrical objects are represented as shown either in (*e*) or in (*f*); in rectangular objects they are shown as in (*g*). The breaks in (*b*) to (*g*), inclusive, show the cross-section of the object. Sometimes, they are also section-lined to indicate the material of the object as in (*h*). To save time it is customary to indicate breaks on structural drawings by means of an irregular freehand line as in (*i*), or by a line drawn with long dashes, as in (*j*) or (*k*); these conventions will be used on all subsequent drawing plates. Sometimes the main lines of the object are stopped abruptly without indicating the break in any special manner, as in (*l*).

The omitted portion of the object is assumed to be of the same size and construction as the parts adjacent to the break. If the parts not shown differ in any way from those drawn, that fact should be made clear by a note. Sometimes, one end of the object is omitted. When the object is symmetrical about its center line, only one-half of it is usually drawn. However, it is good practice to extend the main lines of the object a short distance beyond the center line and indicate a break, in order to make the drawing clearer. Furthermore, a note should be added to call attention to the fact that the object is symmetrical about its center line.

REPRESENTATION OF BOLTS AND NUTS

41. United States Standard.—In structural drawing it is frequently found necessary to represent bolts and nuts. A bolt, Fig. 13 (*a*), is a cylindrical rod that has a formed head at one end and is threaded at the other end to receive a nut, shown in (*b*). To make an accurate drawing of a bolt or nut would require considerable time, because the threads are in the form of a helix, which is a difficult curve to lay out. Therefore, it became necessary to adopt conventional methods for representing bolts and nuts. The proportions of bolts and nuts in this country are fixed by what is known as the United States Standard in order to make all bolts and nuts interchangeable.

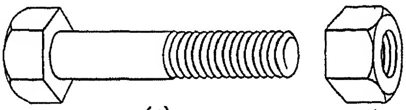

(*a*) (*b*)

FIG. 13

42. Threads.—A plain screw thread on the end of a bolt is shown in Fig. 14 (*a*). In section it is **V** shaped, the sides being inclined 60° with the axis of the bolt, as shown enlarged in section (*b*). The outer edge *a* where the sides of the thread meet is the point of the thread, and the inner point *b* where the adjacent sides meet is the root of the thread. The pitch of a thread is the distance between the points of two adjacent threads measured parallel to the axis of the bolt, as *p*, Fig. 14. The height or depth of a thread is the vertical distance *h* from

the root to the point of the thread. The diameter of the threaded end, as measured between the points of the thread, is the same as the diameter d of the bolt. The *root diameter* d_1 is the distance between the roots of the thread.

The thread most commonly used in this country is the United States Standard thread. It is of the same form as the thread shown in (a) and (b) except that the point in that thread is flattened by one-eighth the height of the thread and the root is raised an equal distance, as shown in enlarged section in (c). A flat point is less liable to break off than a sharp point. The real height of the thread h_1 is $\frac{3}{4}$ h.

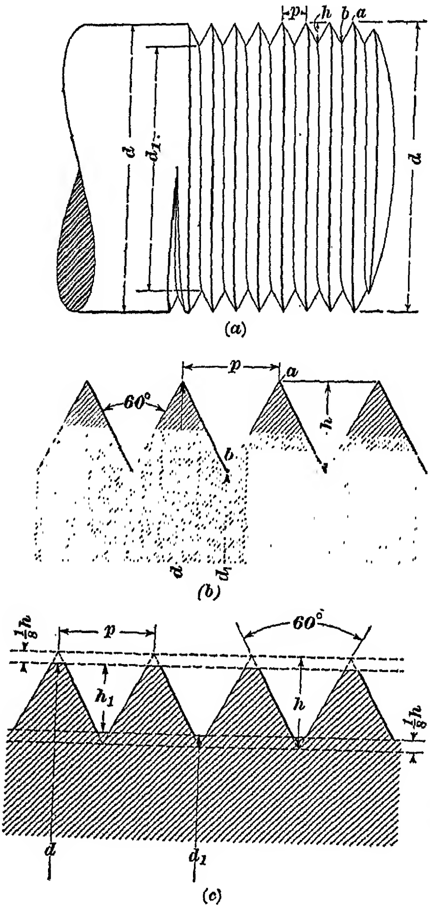
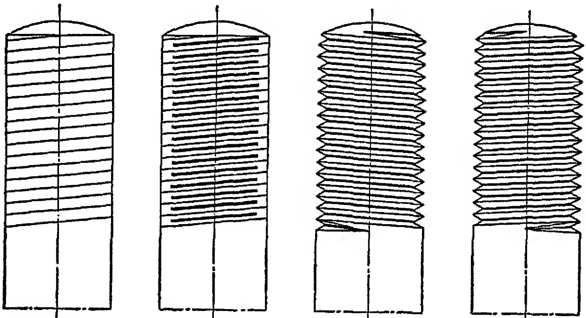


Fig. 14

43. Conventional Methods for Drawing Threads.—In Fig. 15 are shown the conventional methods commonly used in designating the threaded ends of a bolt. The simplest method is shown in (a). It consists of drawing across the bolt single lines spaced the same distance apart as the threads. These lines are inclined half the pitch in one diameter, thus represent-

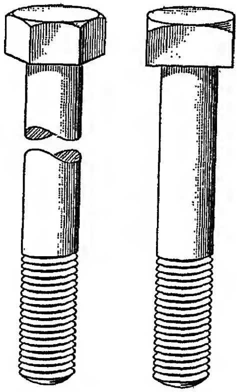
ing approximately the point of the thread. The conventional method shown in (*b*) presents a somewhat neater appearance, the light lines indicating the point of the thread and the heavy



(*a*) (*b*) (*c*) (*d*)

FIG. 15

lines the root of the thread. When it is desired to give the drawing an accurate and finished appearance, it is customary to draw the screw threads as shown in (*c*) and (*d*). It will be observed that the threads slope in opposite directions in (*c*) and (*d*). This method is usually employed to show whether the thread is right-hand or left-hand. A United States Standard bolt provided with a right-hand thread is tightened by turning the nuts in a clockwise direction, while a bolt provided with a left-hand thread is tightened by turning the nut in the opposite direction. Whether the threads of a bolt are right-hand or left-hand may readily be determined by placing the bolt in a horizontal position; if the threads slope from the top to the bottom toward the right, the bolt is cut with a right-hand thread, while if they slant from the top to the bottom toward the left, the bolt is cut with a left-hand thread.



(*a*) (*b*)

FIG. 16

columns are given respectively the height of nut, height of head, and short diameter, or diameter of the inscribed circle, for hexagonal and square bolts; in the sixth column is given the long diameter, or diameter of the circumscribed circle, for a hexagonal nut or head, and in the seventh column the long diameter for a square nut or head. Thus, for a hexagonal or square bolt of 1-inch diameter, the threads per inch are 8, the height of the nut is 1 inch, the height of the head is $\frac{13}{16}$ inch, and the short diameter of the nut or bolt head is $1\frac{5}{8}$ inches. The curve in the central part of the hexagonal nut or bolt is drawn with a 1-inch radius, while the proper radius for the curves in the two side parts is found by trial, their extremities being determined by the dotted lines *a* in the illustration. The curve in the square nut or bolt head is drawn with a radius $c=2$ inches. A detail drawing of the bolt head for a hexagonal bolt 1 inch in diameter is shown in Fig. 18.

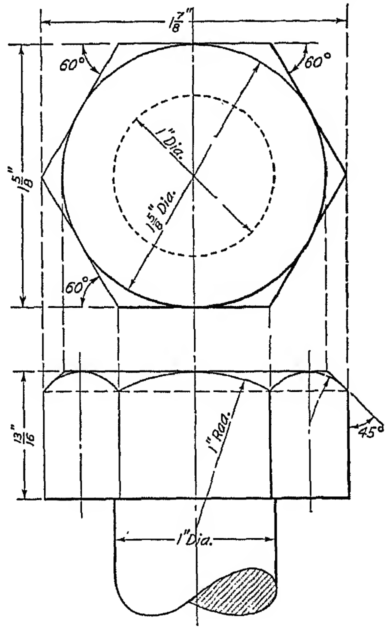


Fig. 18

REPRESENTATION OF STRUCTURAL RIVETS

45. Rivets.—The members of steel structures often consist of two or more pieces held together by structural rivets. Rivets also connect the various members of a structure; they, therefore, constitute important links that require careful attention. The rivets mostly used in steel construction consist of a short cylindrical rod, called a *shank*, and two button heads which are practically hemispherical. An elevation is shown

in Fig. 19 (*a*) and a section in (*b*) of part of a member composed of two steel pieces, known as *angles,* which are riveted together. To form the riveted connection, holes $\frac{1}{16}$ inch larger in diameter than the rivets to be used are first punched or drilled in each angle, and the two angles are placed back to back so that the holes in them match. A red-hot rivet, consisting of a shank and one head is inserted in each hole, as in (*c*), and by the aid of a cup-shaped die the protruding plain end of the rivet is pressed or hammered until another button head is formed.

Sometimes, the button head is in the way of other members. It is then necessary to drill out some of the metal through which the rivet passes in conical form and to press or hammer the rivet head in a flat die so that it fills the hole and is flush with the metal, as in (*d*). Whatever part of the rivet projects

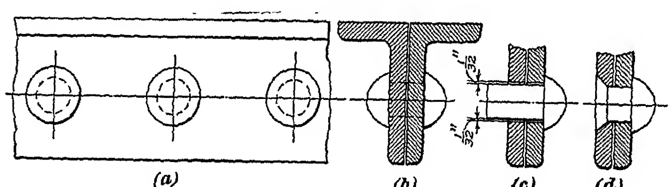


FIG. 19

beyond the metal may be chipped off with a chisel. Such a rivet head is known as a *countersunk head,* and the rivet is known as a *countersunk rivet.* One or both heads of a rivet may be countersunk. Whenever conditions require it, either rivet head or both may be flattened at the top while the rivet is still hot, so that the height of the head does not exceed $\frac{1}{4}$ or $\frac{3}{8}$ inch. Such rivets are known as *flattened rivets.*

46. Conventional Signs.—In Fig. 20 is shown Osborne's code of conventional signs for structural rivets, as used by the leading structural steel companies. The sectional view will help to make clear the meaning of the different signs and the terms full, flattened, countersunk, or countersunk and chipped heads. Rivets that are driven in the shop are called *shop rivets,* and those driven during the erection of the structure, or in the field, are called *field rivets.*

The basis of this system of signs consists of an open circle to represent a shop rivet, a blackened circle to represent a field rivet, a diagonal cross to represent a countersunk head, and a 45-degree diagonal stroke or strokes to represent flattened heads.

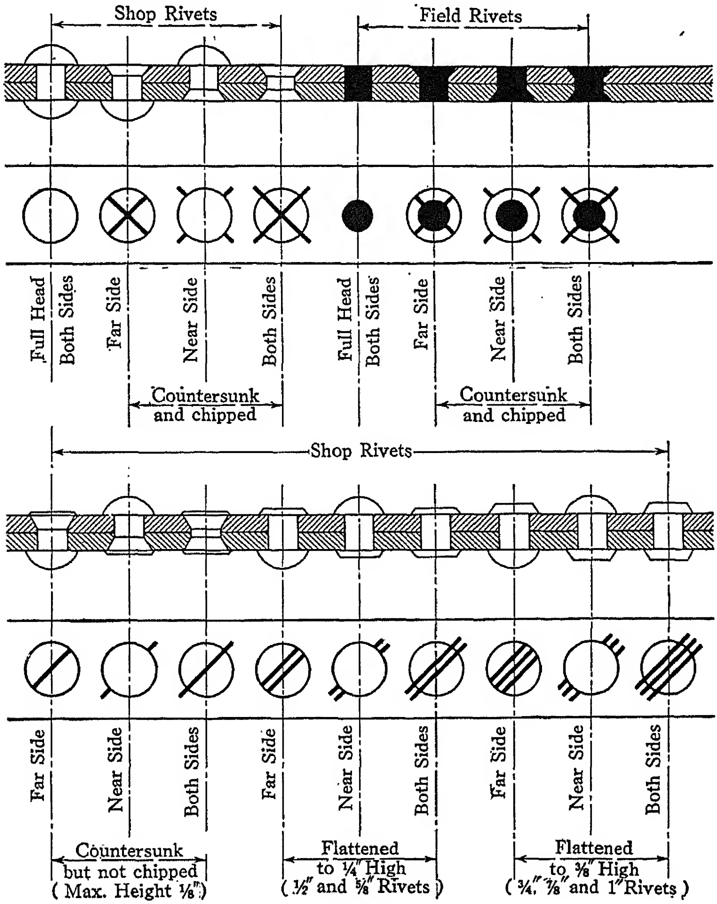
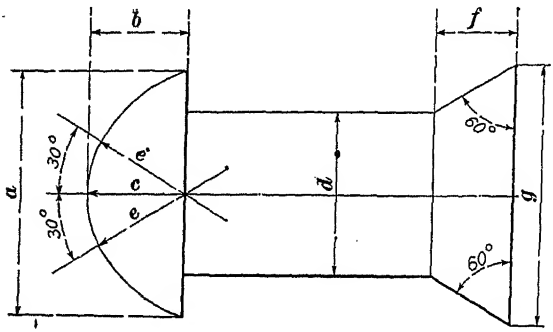


Fig. 20

The circles which represent shop rivets are drawn with a radius equal to that of the rivet heads, while the blackened circles representing field rivets or open holes are drawn with a radius equal to the radius of the holes through which the rivets

pass. The diagonal cross indicates not only that the rivet head is to be countersunk, but also that it is to be chipped off flush with the surrounding material. If the rivet is to be countersunk, but not chipped, the sign indicating *flatten to* $\frac{1}{8}$ *inch* is used. The positions of the diagonal lines with reference to the circle (inside, outside, or both) indicate whether the rivet head is countersunk into the far side (invisible), the near side (visible), or both sides of the material. Similarly, the number and position of the diagonal strokes indicate the height and position of the flattened head. Any combination of



$a = 1.5\,d + \frac{1}{8}''$ $e = 1.5\,b$
$b = .425\,a$ $f = 0.5\,d$
$c = b$ $g = 1.577\,d$

FIG. 21

countersunk and flattened heads for shop or field rivets can be readily indicated by the proper combination of the corresponding signs.

47. Proportions of Rivets.—In Fig. 21 is shown a full-size detail of a structural rivet with one full head and one countersunk head. As will be observed, the full head is not a true hemisphere, since a side view of it is best represented by means of three arcs, the two end arcs being drawn with a radius equal to one and one-half times the height of the rivet head, and the middle arc with a radius equal to the height of the rivet head. Below the diagram of the rivet in the illustration are given the relations of the dimensions of the rivet.

To obviate computations, the proportions of the various rivets used in structural work, based on these relations, are given in Table II at the end of this Section.

VIEWS OF DRAWING

48. Number of Views.—Structural drawing is primarily *projection drawing.* In representing an object a sufficient number of views should be shown to give all the necessary information in the clearest manner. Two or more views are usually required, but when all the information can be clearly given in one view, no more views should be drawn. Thus, for the construction of a simple object like the steel plate shown in Fig. 22 one view is sufficient, while in the detail drawing of the bent plate shown in Fig. 6 three views are required, namely: a top view at (*a*), a side elevation at (*b*), and the section *A-A* at (*c*). In detail drawings of objects of a more complex nature more views may be employed in order to give the workmen in the shop the information necessary to construct the object.

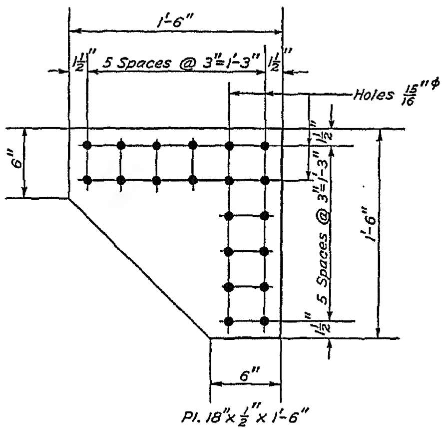


Fig. 22

49. Arrangement of Views.—It is immaterial which view is drawn first, but the relative location of these views should be the same on all drawings. The top view should be placed directly above the front elevation, and the bottom section directly below it. The end view should be placed opposite the front view and near the end it represents. Sections other than the bottom section may be placed in any convenient place near the main views of the object. However, it is best to place a

section opposite the view on which the section plane is indicated, so that the relation between the section and the view will be more apparent.

The views of an object should be placed sufficiently far apart to provide ample space for the dimension lines and the various notes. Crowding of views should be avoided because it makes the drawing more difficult to draw and harder to read.

GENERAL INSTRUCTIONS

DIRECTIONS FOR MAKING PENCIL DRAWINGS

50. General Remarks.—The pencil drawings required in this Section are not inked in, but after each drawing is completed in pencil on paper, it is copied in ink on transparent tracing cloth tacked on the pencil drawing. It is, therefore, essential that the pencil work be executed neatly and made to stand out clearly so that no difficulty will be experienced in tracing it. In many drafting rooms it is customary for one man to make the pencil drawing and for a less experienced man to trace it. The beginner should, therefore, train himself to make a neat and complete pencil drawing in the first place and not to rely on covering up defects in tracing. The art of making a good pencil drawing is more difficult than that of making a good tracing, and it, therefore, requires more pains to acquire the former art than the latter. The beginner should endeavor to make all lettering in pencil neatly, carefully, and exactly as he would want it to appear on the tracing.

51. Essential Rules of Cleanliness.—Before starting the pencil drawing, the draftsman should see that his hands are clean. He should not touch the paper unless it is absolutely necessary, because pencil lines smear easily, and he should never begin work without wiping the drawing board and instruments. In making the drawing some draftsmen first draw all lines lightly with a 6-H pencil, and after the view has thus been completed to their satisfaction, they run over the lines to be inked in on the tracing with a softer pencil. The

same method is followed in lettering. This, of course, consumes considerable time, but when a neat drawing is desired, it is worth while. It is of particular advantage to the begin-

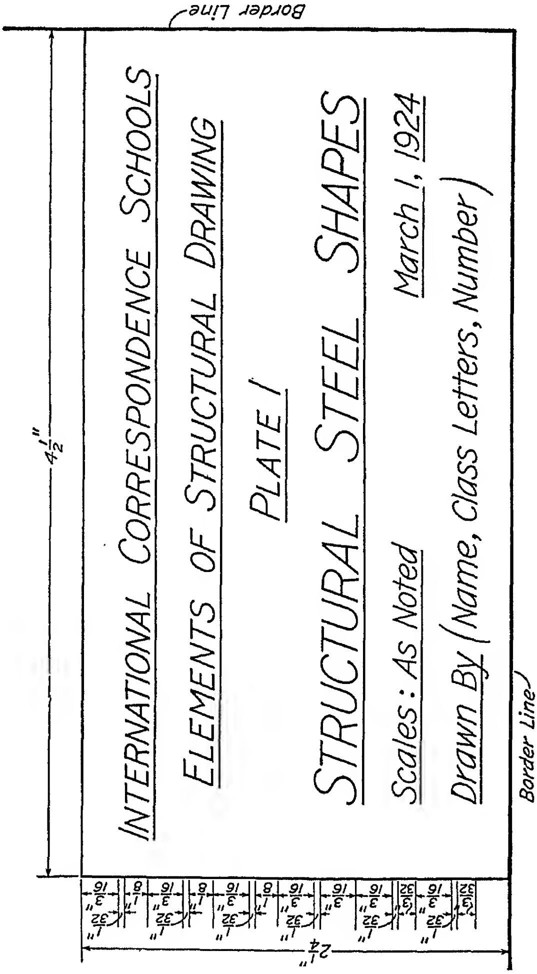


FIG. 23

ner who does much erasing in the early stages of his training, because lines or letters made with a soft pencil, or *dug* into the paper, are hard to erase and usually leave a mark after they have been erased.

52. Size of Drawing Plates.—The drawing plates in this Section are to be 14 inches wide by 18 inches long, with border lines drawn $\frac{1}{2}$ inch from the edges. The working limits of the drawing are, therefore, 13 by 17 inches.

53. Title of Drawing.—Following the usual drafting-room practice, the title of each drawing will be lettered in the lower right-hand corner of the drawing. A space $2\frac{1}{4}$ inches wide by $4\frac{1}{2}$ inches long should be provided for that purpose, and the guide lines for the lettering should be located and ruled as shown in Fig. 23, where the title for Plate 1 is illustrated. The lettering in the title should be properly centered and neatly executed, so as to present an attractive appearance.

54. Dimensions.—All dimensions on the drawings will be shown by continuous fine lines finished with arrowheads at both ends. The dimension figures will be placed immediately above the lines and midway between the arrowheads, as illustrated in Figs. 6 and 22. The dimension lines should be drawn parallel to the sides to be dimensioned, and wherever possible should be placed outside of the illustration to which they apply.

The dimension figures should be carefully printed and not written, and they should be made sufficiently large and distinct to be read with ease. All dimension figures above 12 inches should be expressed in feet and inches, the feet to be designated by a single accent (′), and the inches by a double accent (″); dimensions less than 12 inches should be expressed in inches only. To avoid all possibility of confusion when the single accent for feet is accidentally omitted, the number of feet should be separated by a hyphen, as 8′-$7\frac{3}{4}$″. When there is no integral number of inches in the dimensions, a zero should be inserted for the number of inches. Thus, 11 feet should be printed 11′-0″, and 12 feet and $\frac{3}{8}$ inch should be printed 12′-$0\frac{3}{8}$″. When the dimension figure contains neither feet nor an integral number of inches, the fraction only should be printed, as for example, the dimensions $\frac{3}{4}$″ and $\frac{3}{8}$″ shown in Fig. 6.

The dividing lines of fractions should always be made horizontal, as $\frac{3}{4}$″, $\frac{7}{16}$″, $\frac{15}{16}$″, because the inclined dividing lines often

tend to make the fractions ambiguous. For instance, if the 1 in the numerator of 15/16 were made slightly larger than the remaining figures, the fraction could easily be mistaken for one and five-sixteenths.

DIRECTIONS FOR MAKING TRACINGS

55. Handling Tracing Cloth.—The tracing cloth should never be handled with moist hands, nor should it ever be allowed to come in contact with water. Water dissolves the waxy sizing in the tracing cloth, and leaves an opaque white stain on which the ink spreads and which prints as a white spot on the blueprint. In handling the tracing cloth, care should be taken not to crease it, because the creases show on the blueprint.

56. Inking on Dull Side.—As will be observed, the two sides of the tracing cloth are of different finish. One is glossy and smooth and is known as the glazed side, while the other is somewhat rough and is known as the dull side. In structural drawing, all inking should be done on the dull side, because it is less affected by erasures and offers a better surface for pencil work. Besides, if the tracing is done on the dull side, the cloth is less likely to curl.

57. Removing Selvage Edges.—Tracing cloth expands and contracts with the varying amounts of moisture in the atmosphere. To protect the tracing cloth before it is used, selvage edges, which are not much affected by atmospheric conditions, are woven into the cloth. These edges are from $\frac{1}{8}$ to $\frac{1}{4}$ inch wide, and their limits are usually marked by a colored thread woven into the cloth. Before the tracing is used, the selvage edges should be torn off. Otherwise, the tracing cloth will pucker because of uneven expansion and contraction with atmospheric changes.

58. Preparing Tracing Cloth for Inking.—After the pencil drawing has been completed, place a sheet of tracing cloth over it. Tack one corner down, and after pulling on the corner diagonally opposite, so as to keep the cloth taut between

the two corners, tack it down. Pull on the third corner so as to stretch the cloth evenly between the three corners and tack it down. Then tack down the fourth corner so as to keep the tracing evenly stretched all over. On large tracings six and sometimes eight tacks are advantageously employed for tacking the tracing. Many draftsmen fold the corners of the tracing so that the tacks pass through two thicknesses of cloth, which makes the cloth less liable to tear away from the tacks.

The surface of the tracing cloth is not always in condition to take the ink properly, as it is often somewhat oily in spots over which the ink does not flow readily. To overcome this, before inking is begun, a little powdered chalk or pumice stone, scraped with a knife or file, should be sprinkled on the tracing, rubbed over the entire surface with a clean, soft rag, and then carefully wiped off. Dealers in drawing materials offer for the same purpose specially prepared *tracing powders,* or *pounces,* in convenient tin shakers. Talcum powder may also be used to advantage, but no excess powder should remain on the tracing when inking is begun, or the drawing pen will become easily clogged and inking will be rendered difficult. Besides, where there is an excess of powder, the ink lines wear off readily.

59. Tracing of Drawing.—The drawing should be traced in a systematic manner or much time will be lost in waiting for the lines to dry. In making small tracings that can be finished in one day, it is best to begin by inking all the center lines. On larger tracings the inking should be confined to as much of the drawing as can be completed in one day. The reason is that the tracing cloth expands and contracts with the varying amounts of moisture in the atmosphere, and if the center lines for the entire drawing were inked on one day without inking the other lines, a change in atmospheric conditions over night might throw some of the center lines so much out of place with the pencil lines beneath as to necessitate shifting the tracing. After as many center lines as seem advisable have been inked, all fine circles and curves should be traced, and then all other fine lines such as the projection lines and the dimension lines, but not

the section lining or the fine lines that are tangent to heavy circles or curves. It is always easier to draw tangents to a curve than to draw the straight lines first and then to connect them with a curve.

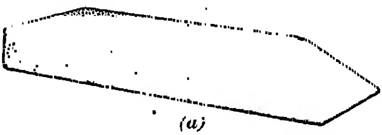
The lines on the tracing should be drawn with a **T** square and triangles in the same manner as they were drawn in pencil. The horizontal lines nearest the top of the sheet should be drawn first, the work proceeding downwards. The vertical lines should then be drawn by beginning at the left end and proceeding to the right. Finally, the inclined lines should be traced. After all fine lines, except the section lining and the tangents to heavy curved lines, have been inked, the heavy lines should be traced in the order specified for the fine lines. To obtain uniformity, all lines of the same width should be inked with one setting of the pen whenever possible.

After all the lines are drawn, the arrowheads of the dimension lines and the dimension figures should be put in, and, finally, the notes and title should be lettered. For all lettering on the tracing, pencil guide lines should be drawn. Freehand lettering only should be employed on structural drawings. As soon as the lettering has been completed, the border line should be drawn. After the drawing has been finished, the tracing should be inverted to see whether ink has passed through holes in the cloth, and whatever blots are found should be carefully removed.

ERASING AND CLEANING

60. Importance of Erasing.—The ability to make erasures carefully and skilfully is one of the qualifications of every good draftsman. Besides the draftsman's errors, that are usually detected in checking and must be corrected before the drawing is sent out, revisions in the design frequently necessitate extensive changes. The draftsman, therefore, must learn how to erase parts of a tracing so that they will not be noticeable without injuring the cloth or the paper in any way. He must realize that erasing, although it is an unpleasant task, is part of his duties, and he must cheerfully do whatever work of that nature is necessary.

61. Erasing Ink From Tracing.—In erasing ink from a tracing, a hard pencil eraser, such as a ruby or emerald eraser, illustrated in Fig. 24 (*a*), should be used in preference to the ink eraser shown in (*b*). Ink erasers are made of rubber mixed with emery or glass and are very effective in removing ink from tracings, but they tend to scratch the surface of the cloth where the erasure is made to such an extent that good inking cannot be done on it afterwards. In using the hard pencil erasers, more time is consumed and the draftsman's patience is more severely tested, but the more satisfactory results obtained make it worth while. However, in using a hard pencil eraser, care should be taken not to overheat the cloth, because the waxy sizing is thereby removed and the cloth rendered opaque. The draftsman should from time to time feel the spot over which the erasing is done, and as soon as the cloth gets warm he should allow it to cool off.



(*a*)

(*b*)

FIG. 24

When erasing on a tracing, the cloth should be laid on a hard, smooth surface and held firmly, the rubbing being done gently and patiently until all traces of ink have disappeared; a rotary motion imparted to the eraser will often facilitate the operation. The gloss on the tracing cloth, if removed by the rubbing, may be restored by applying powdered soapstone with a piece of chamois and then finishing the spot with chamois alone; the rubbed area may also be burnished with a piece of soapstone, ivory burnisher, or, in the absence of other means, with the thumb nail. A knife or steel eraser should never be employed on tracing cloth, because it invariably makes it unfit for taking ink.

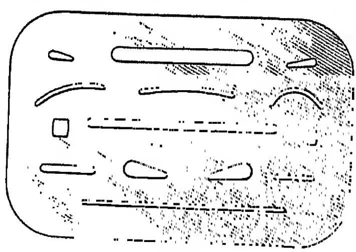


FIG. 25

The erasing shield shown in Fig. 25 will be of great advantage to the draftsman in making careful erasures, especially when it is desired to remove a small portion of a view without affecting the surrounding parts. These shields are made of steel, nickel-plated brass, or xylonite. For extensive use, the steel shield is preferred because of its greater durability, although, unlike the others, it is liable to rust when kept in damp places.

A liquid ink eradicator for removing India ink from tracing cloth is sold by dealers in drawing supplies. However, it is not used extensively because it is of practical value for large erasures only, and it cannot be employed where erasures have previously been made with erasers.

62. Cleaning Tracing.—In erasing pencil marks from a tracing where no inking has been done, a ruby or emerald eraser can be used most effectively. However, when the pencil marks are to be erased from inked portions of the tracing, either a sponge eraser or an art-gum eraser should be employed, because the emerald and ruby erasers tend to remove also the ink lines and notes. The sponge and art-gum erasers can also be used advantageously to give the tracing a general cleaning.

A tracing may be cleaned of all pencil marks or dirt by rubbing its surface with a clean rag or waste dipped in benzine. However, care should be taken to see that the benzine is free from water, because the tracing will be injured by the water. Although the use of benzine saves much time in cleaning tracings, it is not used in many drafting rooms, because it is supposed to injure the cloth to some extent and to affect the ink lines.

63. Erasing and Cleaning Paper Drawings.—For removing ink from paper drawings, ink erasers are generally used. Although their use on paper is not nearly so objectionable as on tracing cloth, they scratch the surface of the paper so that dirt gathers readily where the erasures have been made. Therefore, either a hard pencil eraser should be used exclusively or part of the ink should be removed with an ink eraser and the remainder with a pencil eraser. Pencil lines and let-

tering are most effectively removed from a paper drawing with a ruby or emerald eraser. Where small parts of a view are to be erased, a shield may be employed to protect the remaining parts. Paper drawings are best cleaned of light pencil lines or dirt with sponge or art-gum erasers.

BLUEPRINTING

64. Directions for Making Blueprints.—In Fig. 26 is shown one of the simplest types of printing frames that is often used in the smaller drafting rooms and by beginners in blueprinting. The back of the frame is made in three sections *a*, *b*, and *c*, which are hinged together and held in place by spring clips *d*. In the front of the frame is a large plate glass. In making a blueprint, the frame is placed face down-

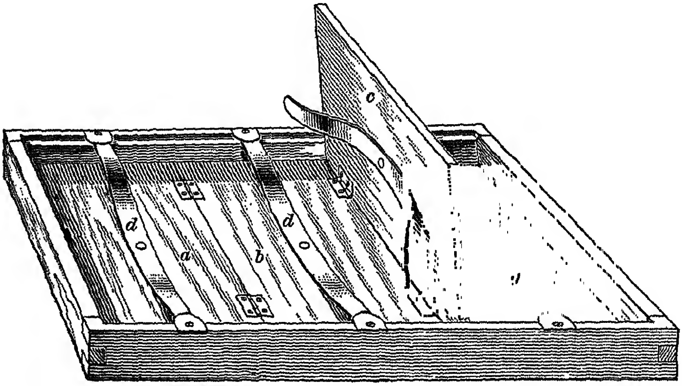


FIG. 26

wards, and after unhooking the clips *d*, the back is removed. The tracing is then laid on the glass *g* with the inked side touching the glass, and a sheet of blueprint paper is laid on the tracing, with the coated side next to the tracing cloth. Both the tracing and paper should be perfectly flat, and care should be taken not to have the corners turned under. A piece of felt or blotting paper is then placed over the blueprint paper and the cover is replaced and securely locked with the clips *d*. This

work should be done in a subdued light in order that the blueprint paper may be kept from the light as much as possible.

The frame is then exposed to sunlight, or a bright electric light, in such a manner that the rays strike the glass squarely. The light shining through the glass and the semitransparent tracing cloth act on the coating of the blueprint paper which is not directly under the inked lines, producing a chemical change that gives the surface of the paper a permanent bluish-gray color. After the print has been exposed to the light for the proper length of time, it is removed from the frame, and, with the sensitive side down, it is immersed in water in a tray or sink sufficiently large for that purpose, where it is allowed to remain for about 5 minutes. The coating is thus removed from all parts of the print which were covered by the ink lines, leaving them white; the remainder of the print assumes a blue color. Overexposed parts may be improved by dipping them for a moment in a solution of sodium bichromate or hydrogen peroxide, and then rinsing thoroughly. After the prints have been washed, they are hung up to dry.

65. Time of Exposure.—The most important point in connection with blueprinting is the time of exposure. If a print is exposed for too short a time, the background, or blue portion, is very pale, and it is difficult to distinguish the lines and letters. If the print is exposed for too long a time, the background becomes dark-blue or purple, and the light penetrates the ink lines, thereby coloring the paper where it should remain unaffected. The time of exposure to sunlight varies with the time of the day, month of the year, and weather conditions, being less for a bright sunshiny day than for a dark cloudy day. It is best to judge the proper time of exposure to the light by the color of the strip of print projecting beyond the edge of the tracing.

To obtain the exact shade of the projecting edge, take a strip of blueprint paper about 12 or 15 inches long and 3 or 4 inches wide. Divide it into 12 or 15 equal parts and number them on the back *1, 2, 3,* etc. Take a piece of tracing cloth, and place the blueprint paper and cloth in the frame in such a

way that the cloth covers one-half the width of the paper. Expose the paper to the light, and at the end of 1 minute cover the part of the strip marked *1* with a thin board or anything that will prevent the light from striking the part covered. At the end of the second minute, cover parts *2* and *1*: at the end

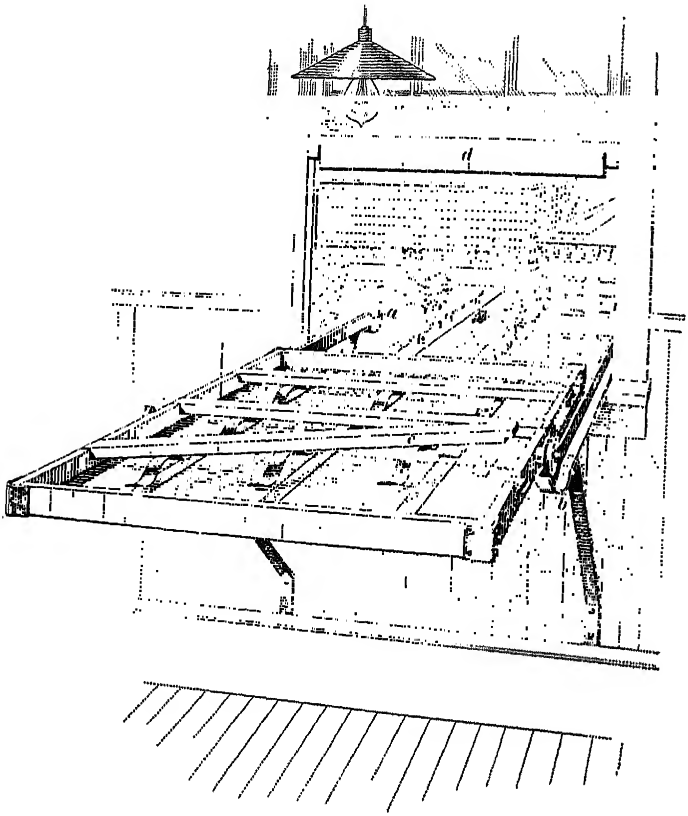


FIG. 27

of the third minute, parts *3*, *2*, and *1*; etc. Part *1* will have been exposed 1 minute; part *2*, 2 minutes; part *3*, 3 minutes, etc. When the whole strip is covered, remove the blueprint paper, cut the parf that was under the tracing cloth from the remainder, and wash the former thoroughly. When it has

dried, select a good, rich shade of blue, and notice the number on the back of this section. Observe carefully the color of the same portion of the remainder of the strip; this is the desired color of the protruding edge and should be kept in mind. All prints should be exposed until the protruding edge attains this color.

66. Blueprinting Apparatus.—For making large blueprints, an apparatus similar to the one shown in Fig. 27 is convenient. This consists of a large printing frame resting on tracks that extend outside a window and have curved ends *a* and *b*. The frame is pivoted on rollers attached to its sides and so placed that they are slightly in front of the center of the frame when the glass side is uppermost; the track is made just long enough so that when the rollers rest in the curve *a* the rear end of the frame rests on the window sill.

The tracing and paper are put in the frame while it is in the position shown in the illustration. After the back and the clamps *c* are in place, the frame, which rests on the rollers in the curved ends *b* of the track, is revolved to bring the glass side uppermost and is pushed out till the rollers rest in the curved ends *a*. After exposure, the frame is drawn in, revolved, and the print taken out.

The window shade should be pulled down while putting in and taking out the paper, to avoid the action of the strong light, which might spoil the paper. A piece of wood fastened to the sash, as at *d*, will make it possible to close the window over the rails. For printing by electric light with the apparatus shown, the frame is turned glass side up but kept inside the room, the inner end being supported by a trestle or other suitable means. A high-candle power incandescent lamp is arranged to swing above the frame, and a hood or reflector concentrates the light on the glass. The lamp is usually kept in motion during the exposure, which will be longer than required for bright sunlight.

67. There are on the market various kinds of electric blueprinting machines which are suitable for offices where

large numbers of prints are required. In the machine shown in Fig. 28 the printing, washing, and drying can be performed in one continuous operation. The blueprint paper *p* passes from the table *a* onto an endless canvas belt moving past a

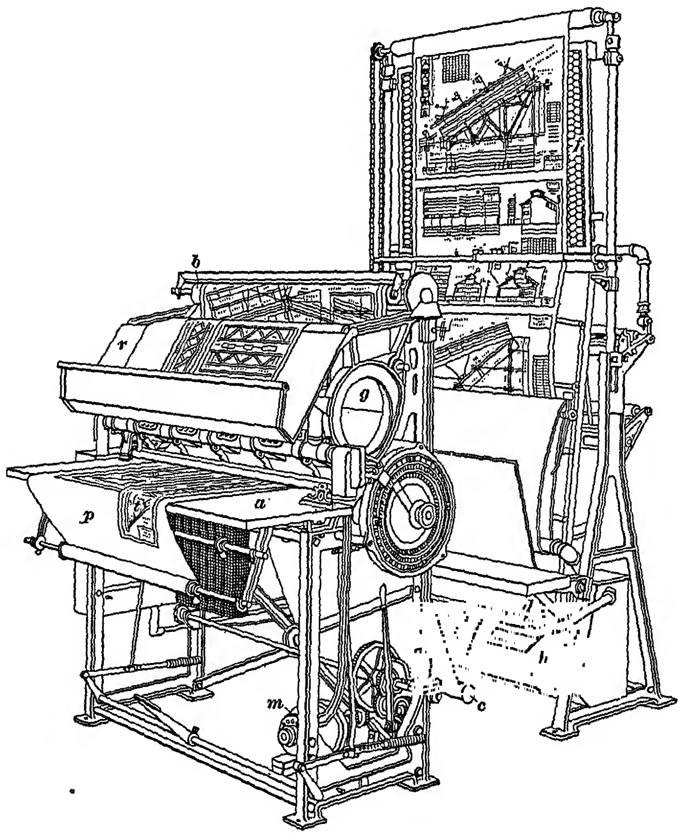


FIG. 28

bank of arc lamps at *g* enclosed by a glass semicylinder. From the belt the print is guided by the rollers *b*, *c*, and *d* to the washing and drying apparatus, where it is washed at *h* and dried by the heat from electric coils at *f*. The tracings *t* are fed on the blueprint paper on table *a* and are thence moved

past the bank of arc lamps, returning into the tray *r*. While moving the tracing and print past the arc lamps, the canvas belt holds the tracing in intimate contact with the blueprint paper on one side and the glass on the other side.

The blueprinting machine can be detached, and used independently, from the washing and drying apparatus, in which case both the tracing and print return to the tray *r*. The power for driving the machine is supplied by the electric motor *m*.

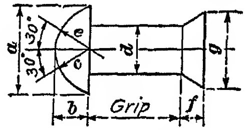
TABLE I

DIMENSIONS IN INCHES OF STANDARD BOLTS AND NUTS

Diameter of Bolt	Threads Per Inch	Hexagonal and Square Nuts and Heads			Long Diameter	
		Height of Nut	Height of Head	Short Diameter	Hexagonal Nut or Head	Square Nut or Head
$\frac{1}{4}$	20	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{11}{16}$
$\frac{3}{8}$	16	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{11}{16}$	$\frac{13}{16}$	1
$\frac{1}{2}$	13	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{7}{8}$	1	$1\frac{1}{4}$
$\frac{5}{8}$	11	$\frac{5}{8}$	$\frac{9}{16}$	$1\frac{1}{16}$	$1\frac{1}{4}$	$1\frac{1}{2}$
$\frac{3}{4}$	10	$\frac{3}{4}$	$\frac{5}{8}$	$1\frac{1}{4}$	$1\frac{7}{16}$	$1\frac{13}{16}$
$\frac{7}{8}$	9	$\frac{7}{8}$	$\frac{3}{4}$	$1\frac{7}{16}$	$1\frac{11}{16}$	$2\frac{1}{16}$
1	8	1	$\frac{13}{16}$	$1\frac{5}{8}$	$1\frac{7}{8}$	$2\frac{5}{16}$
$1\frac{1}{8}$	7	$1\frac{1}{8}$	$\frac{15}{16}$	$1\frac{13}{16}$	$2\frac{1}{8}$	$2\frac{9}{16}$
$1\frac{1}{4}$	7	$1\frac{1}{4}$	1	2	$2\frac{5}{16}$	$2\frac{13}{16}$
$1\frac{3}{8}$	6	$1\frac{3}{8}$	$1\frac{1}{8}$	$2\frac{3}{16}$	$2\frac{9}{16}$	$3\frac{1}{8}$
$1\frac{1}{2}$	6	$1\frac{1}{2}$	$1\frac{3}{16}$	$2\frac{3}{8}$	$2\frac{3}{4}$	$3\frac{3}{8}$
$1\frac{5}{8}$	$5\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{5}{16}$	$2\frac{9}{16}$	3	$3\frac{5}{8}$
$1\frac{3}{4}$	5	$1\frac{3}{4}$	$1\frac{3}{8}$	$2\frac{3}{4}$	$3\frac{3}{16}$	$3\frac{7}{8}$
$1\frac{7}{8}$	5	$1\frac{7}{8}$	$1\frac{1}{2}$	$2\frac{15}{16}$	$3\frac{7}{16}$	$4\frac{3}{16}$
2	$4\frac{1}{2}$	2	$1\frac{9}{16}$	$3\frac{1}{8}$	$3\frac{5}{8}$	$4\frac{7}{16}$
$2\frac{1}{4}$	$4\frac{1}{2}$	$2\frac{1}{4}$	$1\frac{3}{4}$	$3\frac{1}{2}$	$4\frac{1}{16}$	$4\frac{15}{16}$
$2\frac{1}{2}$	4	$2\frac{1}{2}$	$1\frac{15}{16}$	$3\frac{7}{8}$	$4\frac{1}{2}$	$5\frac{1}{2}$
$2\frac{3}{4}$	4	$2\frac{3}{4}$	$2\frac{1}{8}$	$4\frac{1}{4}$	$4\frac{15}{16}$	6
3	$3\frac{1}{2}$	3	$2\frac{5}{16}$	$4\frac{5}{8}$	$5\frac{3}{8}$	$6\frac{9}{16}$

TABLE II

DIMENSIONS IN INCHES OF STRUCTURAL RIVETS



Diameter of Rivet d	Full Head				Countersunk Head	
	Diameter a	Height b	Radius c	Radius e	Diameter g	Depth f
$\frac{3}{8}$	$\frac{11}{16}$	$\frac{19}{64}$	$\frac{19}{64}$	$\frac{7}{16}$	$\frac{19}{32}$	$\frac{3}{16}$
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{25}{32}$	$\frac{1}{4}$
$\frac{5}{8}$	$1\frac{1}{16}$	$\frac{9}{4}$	$\frac{29}{64}$	$\frac{43}{64}$	1	$\frac{5}{16}$
$\frac{3}{4}$	$1\frac{1}{4}$	$\frac{17}{32}$	$\frac{17}{32}$	$\frac{51}{64}$	$1\frac{3}{16}$	$\frac{3}{8}$
$\frac{7}{8}$	$1\frac{7}{16}$	$\frac{39}{64}$	$\frac{39}{64}$	$\frac{59}{64}$	$1\frac{3}{8}$	$\frac{7}{16}$
1	$1\frac{5}{8}$	$\frac{11}{16}$	$\frac{11}{16}$	$1\frac{1}{32}$	$1\frac{9}{16}$	$\frac{1}{2}$
$1\frac{1}{8}$	$1\frac{13}{16}$	$\frac{49}{64}$	$\frac{49}{64}$	$1\frac{5}{32}$	$1\frac{3}{4}$	$\frac{9}{16}$
$1\frac{1}{4}$	2	$\frac{27}{32}$	$\frac{27}{32}$	$1\frac{9}{32}$	$1\frac{31}{32}$	$\frac{5}{8}$

ELEMENTS OF STRUCTURAL DRAWING
(PART 2)

INTRODUCTION

1. The preparation of detailed working drawings for modern steel structures necessitates a familiarity with the typical details of construction of the members of such structures, an acquaintance with the processes of fabricating those members, and a thorough knowledge of the conventional methods generally employed in detailing them. The required information is furnished in this Section. At the beginning is given a brief description of the various steel forms or shapes used in structural-steel work. This is followed by a short discussion of the methods employed in fabricating members of steel structures. The remainder of the Section is devoted to the presentation of the typical details of construction of the various members that compose steel-frame buildings, the proper ways of connecting the members to one another, and the manner of representing them on drawings. In the back of this Section are given Tables I to VIII, inclusive, in which are furnished the standard weights, dimensions, and gauges of steel shapes and data for placing rivets properly. These tables will answer the needs of the student so that he will not have to refer to the handbooks published by steel manufacturers.

In order that the student may apply the information given, he is required to draw four plates, samples of which are included in this Section. The samples are to smaller scales than those of the required plates, and should be used only as a guide in laying out the various parts of the drawings. The plates

should be drawn according to the directions given in the text. Preceding the directions for drawing each plate are given explanations concerning the various parts to be shown. In each case, before beginning a plate, the student should read carefully all explanations that precede the directions for drawing it. After the entire text has been studied and all plates completed, the answers to the Examination Questions should be prepared.

STRUCTURAL-STEEL SHAPES AND MEMBERS

STRUCTURAL-STEEL SHAPES

SHAPES AND THEIR MANUFACTURE

2. Shapes or Sections.—The frames of modern steel structures such as buildings and bridges, are usually made up of elementary standard forms called shapes or sections. The shapes most commonly used in construction are: the *round rod*, the *square* or *flat bar*, and the *plate;* the *angle*, shown in Fig. 1; the *channel*, shown in Fig. 2; the **I** *beam*, shown in Fig. 3 (*a*), and the **H** *section*, shown in Fig. 3 (*b*). The *eyebar*, shown in Fig. 4, is extensively used in bridge construction, but seldom in building construction. The *tee*, shown in Fig. 5, and the *zee*, shown in Fig. 6, were formerly used to a great extent, but at present the tee finds only a limited application and the zee has become practically obsolete. There are numerous other shapes rolled by the various manufacturers, but they are not in general use and hence will not be considered here.

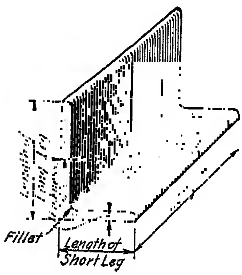


Fig. 1

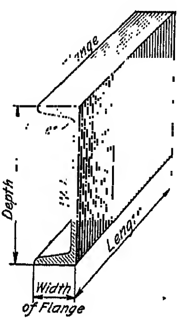
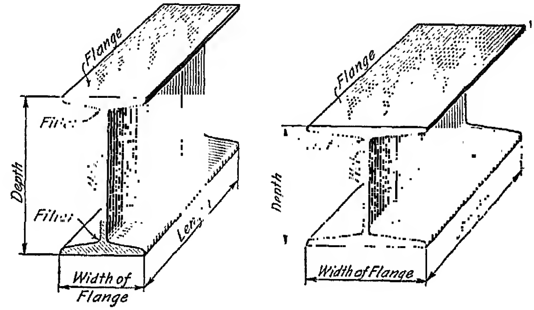


Fig. 2

3. Manufacture of Shapes.—The various steel shapes are manufactured of structural steel which is usually made by the



(a) (b)

FIG. 3

open-hearth process. Steel made by the Bessemer process is of a quality inferior to that of open-hearth steel and is not considered sufficiently reliable for the more important structures.

To produce structural steel, the iron ore is first melted in the blast furnace and reduced to *pig iron*. The pig iron is further refined in an open-hearth furnace, from which the molten metal is tapped into large ladles

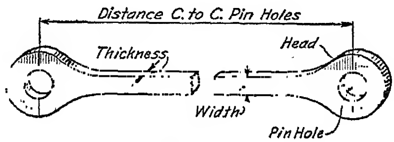


FIG. 4

where the proper amounts of carbon and other ingredients are added to give the resulting steel the desired composition. From the ladles the steel is poured into rectangular molds,

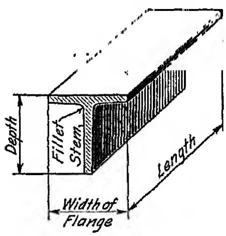


FIG. 5

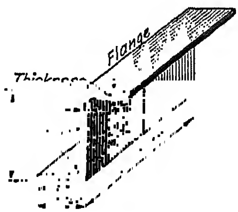


FIG. 6

known as *ingot molds*, where it is allowed to cool sufficiently to permit its handling. These ingots, or rectangular prisms of

steel, when received at the mill, are placed in hot ovens called *soaking pits* where they are heated to a high temperature which renders the material sufficiently plastic for rolling. The heated ingots are then passed through a set of rolls, called *blooming rolls*, where the material is flattened out and given its general shape, rectangular or square. The next step is to pass the material through *roughing rolls*, illustrated in Fig. 7, where it is roughly shaped to the desired form in the grooves between the rolls. The rough shapes are finally passed to the *finishing rolls* where they are finished to the desired dimensions. While yet red hot, the finished shapes, except plates, are passed on by movable tables to circular saws where they are cut to convenient lengths or those indicated on the bills of materials prepared in the drafting-room.

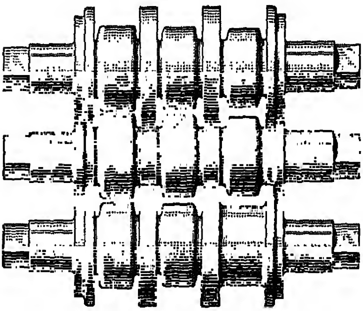


Fig. 7

4. American Standard Sections.—In former years each mill rolled its own peculiar sizes and shapes, which made it inconvenient to use sections from different mills for the same structure. At present, all mills manufacture the same standard shapes of identical dimensions and properties, known as the American Standard Sections, which were adopted by the Association of American Steel Manufacturers. Every mill also manufactures special shapes, which are different in different mills. These special shapes are usually harder to obtain than the standard shapes, and therefore most designers specify only standard shapes, in their designs. The so-called *Bethlehem shapes*, manufactured by the Bethlehem Steel Company, Bethlehem, Pa., are rolled by a special process, and their dimensions and properties differ from the standard sections. In rolling Bethlehem shapes, four rolls are employed, two horizontal and two vertical, instead of the grooved rolls shown in Fig. 7.

The sizes and properties of the standard sections may be found in the handbooks published by the various steel manufacturers. However, since in the process of rolling the shapes the rolls wear somewhat, slight variations in the actual sizes of the shapes from those given in the handbooks may always be expected.

Plates are rolled either with horizontal rolls only, and the edges then sheared off, or with two vertical and two horizontal rolls in what is known as a *Universal Mill*. Plates with sheared edges are rolled up to 150 inches in width, but Universal Mill plates, commonly designated as *U. M. plates*, are rolled up to a width of 60 inches. The Universal Mill plates, having smooth and even edges, are suitable for more important work where the plates are exposed to public view. The thicknesses of plates used for structural purposes vary from $\frac{3}{16}$ inch to $2\frac{1}{4}$ inches.

PLATE 1: STRUCTURAL-STEEL SHAPES

5. Dimensions of Shapes.—Since the dimensions of the various standard or special shapes are practically fixed, it is not necessary to show the dimensions on drawings. The proper shape need merely be specified by a suitable reference note, as will be shown later. However, in order to acquaint the beginner with the appearance of some of the standard shapes and the methods of representing them in various views, detail drawings of these shapes are given in the accompanying sample Plate 1, which is now to be drawn. Wherever in this Section reference is made to a figure number on a Plate, the number is printed in blackface type, in order that it may be readily distinguished from the figure numbers in the text. The following explanations should be carefully studied before beginning the work of drawing the Plate.

6. Angle.—In Fig. **1** of Plate 1 are shown the details of an angle drawn to a scale of $1\frac{1}{2}$ inches = 1 foot, *A* being a top view, *B* a front elevation, and *C* an end view. The cross-sectional area of the angle resembles the letter **L**; hence on structural drawings an angle is designated as **L**. The two

parts composing the angle are called *legs*. There are two types of angles manufactured; those having legs of equal length which are commonly known as *equal angles*, and those having legs of unequal lengths which are known as *unequal angles*.

The inside corners of the legs are rounded. The intersection of the inside faces is also rounded, the round part being known as the *fillet*. In order to avoid spending time on unnecessary refinements, it is the general practice among structural draftsmen to show these rounded parts freehand or to omit them entirely, showing the edges square.

In structural drawing, it is customary to specify an angle by giving the length of its legs in inches, the thickness of the legs in inches, and the length of the section in feet and inches; in an unequal angle, the length of the longer leg should be given first. Thus, the angle in Fig. 1 is specified as **L** *6″×4″×¾″×2′-2″*, **L** being the designation for angle, *6″* the length of the long leg, *4″* the length of the short leg, *¾″* the thickness of the legs, and *2′-2″* the length of the shape.

In Table I at the end of this Section are given the sizes and weights per foot length of equal angles, and in Table II the sizes and weights per foot length of unequal angles.

7. Channel.—In Fig. 2 are shown a top view *A*, a front elevation *B*, a bottom-sectional view *C*, and an end view *D*, of a standard channel. The upper and lower parts of the channel are known as the *flanges*, and the part connecting them is called the *web*. The flanges of all standard channels are trapezoidal in section, the inner sides having a slope of 2 inches vertical in 12 inches horizontal.

Channels are rolled in different heights and sizes, but in specifying a particular channel it is merely necessary to state its height, or depth, in inches, its weight per linear foot, and the length of the section in feet and inches. Thus, in Fig. 2 the channel is specified as ⊔ *10″×15.3# ×2′-1½″*, where ⊔ is the standard symbol for channel, *10″* is the depth of the channel, *15.3#* is the weight of the section in pounds per foot, and *2′-1½″* is the length of the channel in feet and inches. In some offices it is customary to designate a channel either by

the symbol [or ⊔, the symbol [denoting that the channel frames with its web vertical and the symbol ⊔ that it frames with its web horizontal.

There are two types of channels, structural and ship-building channels. As their names imply, the former are used in structural work and the latter in building ships. Only the former will be here considered. The principal dimensions and properties of standard structural channels are given in Table III.

8. I Beams.—The details of a standard I beam are shown in Fig. 3 by a top view *A*, a front elevation *B*, a bottom-sectional view *C*, and an end view *D*. The I beam derives its name from the appearance of its cross-section which resembles the letter **I**. It consists of two flanges connected by a web. The inner sides of the flanges of all standard **I** beams slope 2 inches vertical in 12 inches horizontal.

The size of an **I** beam is specified by giving its depth in inches, weight per foot in pounds, and length in feet and inches. Thus, the **I** beam in Fig. 3 is specified as **I** *9″×21.8# ×2′–9″*, the symbol for **I** beam being **I.** The principal dimensions and properties of standard **I** beams are given in Table IV.

9. Zee.—In Fig. 4 are shown the details of a zee, which derives its name from the fact that its cross-section resembles the letter **Z.** In former years the zee was used extensively in column construction, but at present it finds a limited use, and that mostly in roof construction. It is made up of two flanges and a web, all three being of uniform thickness. In specifying the size of a zee it is customary to give its depth, width of flange, and thickness of metal, in inches, and its length in feet and inches. In Fig. 4 the size of zee is specified as **Z** $6''\times 3\frac{1}{2}''\times\frac{9}{16}''\times 1'\text{–}11\frac{1}{4}''$, where **Z** is the standard symbol for a zee, $6''$ the depth of section, $3\frac{1}{2}''$ the width of flange, $\frac{9}{16}''$ the thickness of metal, and $1'\text{–}11\frac{1}{4}''$ the length of the shape.

10. Tee.—The cross-section of the standard tee, detailed in Fig. 5, resembles the letter **T.** The top part of the section is called its *flange* and the lower part its *stem*. There are two types of tees, those having a width of flange equal to the depth

of stem, which are known as *equal tees*, and those having a width of flange greater or less than the depth of stem, which are known as *unequal tees*. Both the flange and the stem have sloping sides. The size of a tee is specified by stating the width of the flange and depth of the stem in inches, the weight of the section in pounds per foot, and the length of the shape in feet and inches. In Fig. 5, the size is specified as **T** *4″×4″ ×13.5 # ×2′–9½″*, which indicates that the section is a tee, the width of flange of which is 4 inches, the depth of stem 4 inches, the weight per linear foot 13.5 pounds, and the length 2 feet 9½ inches.

The use of the tee is diminishing every year. It is not an economical section for the ordinary uses in structural-steel construction, and its application is limited mostly to special types of construction.

11. Eyebar.—In Fig. 6 are shown a plan view *A* and a side view *B* of an ordinary eyebar. In both views the bar is shown broken at the middle, a section through the bar being shown between the breaks in the plan view. The eyebar consists of the two round parts, called *heads*, connected by the bar. In manufacturing the eyebar, a plain bar of uniform width and thickness is first rolled by the usual process. The ends of the bar are then heated and, by special tools, upset and shaped into circular heads, the thickness remaining the same. In the centers of the heads are bored the *pin holes* for connecting the eyebar to the other members of the structure by means of pins.

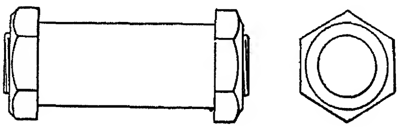


FIG. 8

Eyebars are used mainly in bridge construction, where they serve as tension members in bridges and are connected by means of pins. A pin is a short cylindrical rod threaded at both ends to receive nuts, as illustrated in Fig. 8 in the text.

The size of an eyebar is usually specified by giving the width and thickness of the bar in inches, and the distance between the centers of the pin holes in feet and inches. Thus,

in Fig. 6 the size of the eyebar is specified as *Eye Bar 5″×¾″ ×16′–5″ C. C. Holes*. In specifying the size of hole that is to be bored in the head of the eyebar it is better to give the diameter of the pin for which the hole is to be bored than the required diameter of hole. In good construction the pin holes are bored accurately, so that for pins less than 5 inches in diameter the diameter of the pin hole does not exceed the diameter of the pin by more than $\frac{1}{50}$ inch, and for pins over 5 inches in diameter by more than $\frac{1}{32}$ inch.

12. Rivet.—In Fig. 7 is shown a detail of a structural rivet with one full head and one countersunk head. The diameter of the shank being ¾ inch, the rivet is known as a ¾-inch rivet. The various dimensions of the rivet may be obtained either from Fig. 21 or Table II of *Elements of Structural Drawing*, Part 1. The total thickness of the metal held by the rivet is known as the *grip*. In Fig. 7, Plate 1, the grip is the distance between the under side of the button head and the outside of the countersunk head.

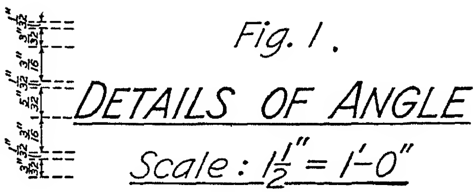


FIG. 9

13. Bolts and Nuts.—In structural-steel work bolts are used mainly for temporary connections, but they are often also used for permanent connections. The two types of bolts mostly used for structural purposes, the hexagonal and the square bolts, are shown in Figs. 8 and 9, respectively. The dimensions for these bolts may be obtained either from Fig. 17 or Table I of *Elements of Structural Drawing*, Part 1.

14. Directions for Drawing Plate 1.—Draw the edges of the plate to form a rectangle 14 inches wide by 18 inches long, and locate the border lines ½ inch from the edges, forming a rectangle 13 inches wide by 17 inches long. In the lower right-hand corner of the plate, inside the boundary lines, lay off the space for the title, 2¼ inches wide by 4½ inches long.

Commence the plate by drawing Fig. 1 in the upper left-hand corner. First draw the light horizontal line *a c* of indefinite length $2\frac{1}{4}$ inches, full size, from the upper border line, and a vertical line *d e* $1\frac{5}{8}$ inches from the left-hand border line. Using a scale of $1\frac{1}{2}$ inches = 1 foot, lay off the length of the angle $dc = 2$ feet 2 inches, and through *c* draw a light vertical line *c k* of indefinite length. With the same scale, lay off the width of the longer leg of the angle $dg = 6$ inches, and the thickness of the shorter leg $df = \frac{3}{4}$ inch. Draw horizontal lines through points *f* and *g* between lines *d g* and *c k*, thereby completing the front elevation *B* of the angle.

The next view to be drawn is the end view *C*. Project the line *k g* and draw the line *a b* $\frac{3}{4}$ inch, full size, from the left-hand border line. Using the scale of $1\frac{1}{2}$ inches = 1 foot, lay off from *a* the 4-inch leg of the angle and project the thickness of that leg from view *B*; lay off the thickness of the 6-inch leg by a vertical line drawn $\frac{3}{4}$ inch to scale from *a b*. Draw in freehand the quarter circles *l* and *m* to represent the curved edges of the legs, and the curve *s* to represent the fillet of the angle, the use of compasses for such small circles being attended with difficulty.

After view *C* has been completed, draw view *A*. First project lines *d g* and *c k*, and lay off the light horizontal line *e n* $\frac{1}{2}$ inch, full size, from the upper border line. From *e* lay off to scale the thickness of the angle, $\frac{3}{4}$ inch, and the width of the shorter leg $eh = 4$ inches. Draw horizontal lines through those points between the prolongations of lines *d g* and *c k*, thereby completing view *A*.

After the three views have been completed in light pencil lines, run over their outlines with heavier lines in order to make them stand out more clearly. Then draw the dimension lines in the same relative positions as shown on the sample Plate and letter the dimension figures neatly and legibly. Complete Fig. 1 by lettering the title of the figure, drawing guide lines as illustrated in Fig. 9 in the text.

15. Begin Fig. 2 by drawing the light horizontal line *e b* $2\frac{5}{8}$ inches, full size, from the upper border line and a light

vertical line *a c* $7\frac{1}{8}$ inches from the left-hand border line. Using a scale of $1\frac{1}{2}$ inches = 1 foot, lay off from *a* along *e b* the length of the channel, 2 feet $1\frac{1}{2}$ inches, and along *a c* the depth of the channel, 10 inches. Draw through *b* a vertical line *b d* of indefinite length, and through *c* a horizontal line ending in line *b d*. Draw horizontal lines located $\frac{1}{4}$ inch below line *c d* and $\frac{1}{4}$ inch above line *a b* to represent the thickness of the ends of the flanges. The front elevation *B* is thus completed.

Begin the end view *D* by projecting the line *c d* to the left and laying off the line *e f*, the back of the channel, 6 inches, full size, from the left-hand border line. Draw the inside edge of the web parallel to the back of the channel, and located $\frac{1}{4}$ inch from it to the scale of $1\frac{1}{2}$ inches = 1 foot. Lay off from *f* and *e* $2\frac{5}{8}$ inches, the widths of the flanges, and from *g* and *h* draw the ends of the flanges $\frac{1}{4}$ inch thick. From the inside edges of the flanges draw lines sloping 2 inches vertical in 12 inches horizontal, which lines should intersect the inside of the web $\frac{5}{8}$ inch from the lines *g f* and *h e*. At the intersection of the inside faces of the flanges with the inside of the web, draw freehand the $\frac{5}{16}$ inch radius arcs which constitute the fillets, thus completing the end view *D*.

In drawing the top view *A*, lay off point *k* along the prolongation of line *a c* $\frac{1}{2}$ inch, full size, from the top border line; the thickness of the web $\frac{1}{4}$ inch, to scale, from point *k*; and the width of the flange $2\frac{5}{8}$ inches, to scale. Draw the full lines *k m* and *n p*, and the dotted line to represent the inside edge of the web which is invisible. The view *A* is thus completed.

The bottom-sectional view *C* represents a horizontal section taken through the web, as it would appear to a person looking downwards. To represent that view, draw the line *r s* $\frac{1}{2}$ inch, full size, from the line *a b*, lay off below point *r* on the downward prolongation of line *a c* the thickness of web and the width of flange to scale, and draw full lines through the points located, ending in the downward prolongation of line *b d*. The web is usually blackened in or section-lined to show that it is in section, although in many offices it is the custom to omit the blackening or section lining and to represent the web by means of two full lines.

After the four views of the channel have been completed, draw the dimension lines and letter the dimension figures. Finally letter the title of the figure in the same manner as previously described for Fig. 1.

16. To draw Fig. 3, first locate line *a b* $\frac{1}{2}$ inch from the right-hand border line, and line *a n* $2\frac{3}{4}$ inches from the top border line. Lay off along line *a n* the length of the **I** beam, or 2 feet 9 inches, to the scale of $1\frac{1}{2}$ inches = 1 foot. Following the dimensions given on the sample drawing, complete the front elevation *B*.

Begin the end view *D* by drawing the center line *e n* of the beam at a distance of $5\frac{1}{2}$ inches, full size, from the right-hand border line. Project the line *b d* and lay off on each side of the center line *e n* $2\frac{3}{16}$ inches, to the scale of $1\frac{1}{2}$ inches = 1 foot, as accurately as the scale will permit, thus laying off the width of the flanges. Represent the web of the beam by means of two vertical lines, located $\frac{5}{32}$ inch on each side of the center line, the web thickness being $\frac{5}{16}$ inch. From the extremities of the outside faces of the flanges lay off the ends $\frac{5}{16}$ inch thick and draw the inside faces of the flanges to slope 2 inches vertical in 12 inches horizontal. The inside faces of the flanges intersect the web at a distance of $\frac{5}{8}$ inch from the outside faces of the flanges. Finally, sketch the fillets, completing the view.

To draw the top view *A*, project the line *c d* and lay off the center line *p t* $\frac{3}{4}$ inch, full size, from the upper border line. Lay off one-half the web thickness and one-half the flange width on each side of the center line, and draw the web in dotted lines and the ends of the top flange in full lines.

The bottom-sectional view *C* is laid out in the same manner as the top view *A*, the center line of the beam being first located $\frac{3}{4}$ inch, full size, from line *a c*. The web, being in section, may be blackened in or represented by two full lines.

Finally, dimension the figure and draw the title for it, as shown on the sample Plate.

17. Proceed with Fig. 4, which may be laid out without much difficulty from the dimensions given on the sample Plate.

First draw a vertical line $a\,b$ $\frac{1}{2}$ inch, full size, from the right-hand border line, and the horizontal line $a\,n$ 5 inches from the lower border line. Lay off along $a\,n$ the distance $a\,c = 1$ foot $11\frac{1}{4}$ inches, to scale, and through c draw the vertical line $c\,d$. From c lay off to scale the depth $c\,d = 6$ inches, and draw line $d\,b$. Show the visible inside edge of the upper flange by a full line drawn at a distance of $\frac{9}{16}$ inch below line $d\,b$, the invisible inside edge of the lower flange by a dotted line $\frac{9}{16}$ inch above line $a\,c$, and complete view B.

Next draw view D, laying off point e $4\frac{1}{2}$ inches from the right-hand border line, and drawing the view according to the dimensions shown.

In drawing the top view A, first draw the top flange $f\,g\,h\,k$, laying off line $f\,g$ 1 inch, full size, from $d\,b$. Show the invisible side of the web by a dotted line $\frac{9}{16}$ inch, to scale, below $f\,g$, and the edge $r\,s$ of the bottom flange of the zee by a full horizontal line $6\frac{7}{16}$ inches to scale above the line $k\,h$.

The view C being a horizontal section, taken through the web and viewed in a downward direction, will show the web in section and the lower flange in plan view. In laying out that view, draw the line $o\,p$ 1 inch, full size, from $c\,a$, and complete the view according to the dimensions shown on the sample Plate. Complete the figure by lettering the dimensions and title.

18. Fig. 5 is the next figure to be drawn. Lay out the front elevation B by drawing the top of the flange $a\,b$ $6\frac{3}{4}$ inches, full size, from the upper border line, and the line $b\,c$ 6 inches from the right-hand border line. Parallel to $a\,b$ and $\frac{1}{2}$ inch below it, to the scale of $1\frac{1}{2}$ inches $= 1$ foot, draw the lower edge of the flange, which corresponds to the edge e in view C.

After view B is completed proceed with view C. First draw the center line $f\,g$ of the tee $\frac{3}{4}$ inch, full size, from $a\,d$; project line $a\,b$ and lay off 2 inches to scale on each side of the center line, thus laying off the 4-inch width of the flange. Draw the ends of the flange $\frac{1}{2}$ inch thick. Project the line $c\,d$ and on it lay off $\frac{1}{4}$ inch on each side of the center line, or

$\frac{1}{2}$ inch, for the thickness of the end of the stem. Since both sides of the flange and stem slope, before the view can be completed the imaginary intersections of the sides of the stem and the inside faces of the flange must first be located at $\frac{9}{16}$ inch below the top of the flange and $\frac{9}{32}$ inch on each side of the center line. Join the lower edges of the flange and stem to these intersections and sketch the fillets, completing the view.

The top view *A* is drawn by projecting lines *a d* and *b c* upwards, drawing the center line *h k* $\frac{3}{4}$ inch, full size, from *a b*, laying off 2 inches to scale on each side of the center line to locate the ends of the flange, and $\frac{9}{32}$ inch on each side to represent the thickness of the stem below the flange. The figure can then be completed as shown on the sample drawing.

19. In Fig. 6 the eyebar is shown broken at the center and the ends brought together. Hence, the distance *a b* between the centers of the heads will not be to scale; all other parts, however, are drawn to the scale of $1\frac{1}{2}$ inches = 1 foot.

Begin the figure by drawing the center line *a b* of the plan view *A* $3\frac{1}{8}$ inches, full size, from the lower border line. Locate point *b* $5\frac{5}{8}$ inches and point *a* $10\frac{1}{4}$ inches, full size, from the right-hand border line. Through points *a* and *b* draw the vertical center lines. With *a* and *b* as centers and a radius of $2\frac{9}{16}$ inches, to the scale of $1\frac{1}{2}$ inches = 1 foot, draw circles to represent the pin holes. Lay off the width of the bar, $2\frac{1}{2}$ inches on each side of the center line *a b*, and draw lines parallel to *a b* to represent the edges of the bar. The arcs that join the straight edges of the bar to the outlines of the heads are constructed in the same manner as arc *m k*, the construction of which is as follows: Draw the construction line *g h* at a distance equal to the diameter of the head, or 1 foot 0 inches, from the edge *o m* and parallel to it. With *b* as a center and a radius equal to one and one-half times the diameter of the head, or 1 foot 6 inches, draw an arc *s t* intersecting the line *g h* at *n*. This point of intersection is the center for the arc *m k* of 1 foot 0 inches radius which joins the edge of the bar to the circular outline of the head. The point of junction *m* of the arc *m k* and the straight edge *o m* is determined by drawing the

perpendicular *n m* from the center *n* to the straight edge. In a similar manner draw the other arcs that join the straight edges of the bar to the outlines of the heads. Finally, complete the outlines of the heads by means of arcs drawn with a 6-inch radius from *a* and *b* as centers. The point *k* where the arc *m k* terminates is on the line *n b*.

About midway between the pin holes show a break in the bar by means of irregular lines spaced about $\frac{1}{2}$ inch, full size, apart. Between the broken lines show a cross-section of the bar, a cross-hatched rectangle 5 inches deep and $\frac{3}{4}$ inch wide, to scale.

The edge view *B* of the bar is then projected from the plan view and drawn $\frac{3}{4}$ inch thick, and the pin holes are shown in side view by means of dotted lines.

20. To detail the $\frac{3}{4}$-inch rivet in Fig. 7, first draw the center line *a b* $5\frac{1}{4}$ inches from the upper border line; and, $1\frac{7}{8}$ inches from the left-hand border line, draw line *c d* of indefinite length. From *o* lay off the grip *o b* of the rivet, which is different for different members but is here assumed as $1\frac{7}{16}$ inches. Lay off from *b* the height of the countersunk head *b f*, which, according to Table II in *Elements of Structural Drawing*, Part 1, is $\frac{3}{8}$ inch. Draw vertical lines through points *o*, *f*, and *b*; and on each side of the center line lay off one-half of the diameter of the rivet, or $\frac{3}{8}$ inch, and draw the outline of the shank. From *g* and *h* draw lines inclined 60° with the vertical intersecting the vertical line through *b* at *k* and *l*. According to Table II, the distance *k l*, the diameter of the countersunk head, should scale $1\frac{3}{16}$ inches.

Draw the full head next. Lay off along *d c*, on each side of the center line, one-half of the diameter of the rivet head, or $\frac{5}{8}$ inch. From point *o* draw lines *o e* and *o n*, making 30-degree angles with the center line; and with *o* as a center and a radius of $\frac{17}{32}$ inch draw the arc *e a n*. Project the lines *e o* and *n o* to points *m* and *p*, so that the length of each line is $\frac{51}{64}$ inch. With a radius of $\frac{51}{64}$ inch draw the arc *e c* with *m* as a center, and the arc *n d* with *p* as a center, completing the outline of the rivet. Add the dimensions and title, and complete the figure.

21. With the information given in Table I of *Elements of Structural Drawing*, Part 1, the bolts in Figs. 8 and 9 may be detailed. First draw the vertical center line *a b* of Fig. 8 at a distance of $1\frac{3}{4}$ inches from the left-hand border line, and at a distance of $4\frac{1}{2}$ inches from the lower border line draw the center line *c d* of the plan view. With *o* as a center and a radius of $\frac{1}{2}$ inch, to half-size scale, draw the circle *e* representing the top view of the bolt, and with a radius of $\frac{13}{16}$ inch draw the circle *f*. Construct the hexagon *g* around the circle *f*, and project the extremities of its sides downwards. In the elevation, draw the under side *h i* of the nut at a distance of 3 inches from the lower border line, and the top of the nut 1 inch, to scale, from *h i*. With the midpoint of *h i* as a center and with a radius of 1 inch, to scale, draw an arc intersecting the projected edges of the nut at *m* and *n*, and through these points draw a horizontal construction line intersecting the outside edges of the nut at *p* and *r*. Bisect the distances *m r* and *n p* and through the midpoints draw vertical construction lines. By successive trials, obtain a radius that will produce an arc that will join points *n* and *p* and will be tangent to the top of the nut. In this case the radius is found to be $\frac{5}{32}$ inch. Draw a similar arc between the points *r* and *m*. Join points *r* and *p* to the top of the bolt by means of short lines inclined 45 degrees with the horizontal. After the nut has thus been completed, lay off to scale from the line *h i* along the line *a b* the grip of the bolt, which in this case will be assumed as $1\frac{1}{2}$ inches. Draw the line *j k* and construct the head of the bolt in a manner similar to that described for the nut. Draw the bolt 1-inch diameter to scale, show the end *s t* of the bolt by means of an arc of 1-inch radius, and sketch the threads by the methods described in *Elements of Structural Drawing*, Part 1.

To construct Fig. 9, draw the center line *a b* $3\frac{7}{8}$ inches from the left-hand border line, and the center line *c d* in the prolongation of line *c d* of Fig. 8. The details of the square bolt may now be completed by following the dimensions given on the sample drawing, which dimensions were obtained from Table I in *Elements of Structural Drawing*, Part 1.

After all figures on the plate have been completed, letter the title of the plate as shown in Fig. 23 in *Elements of Structural Drawing*, Part 1. After the pencil work of the plate is completed, it should be copied in ink on tracing cloth, following carefully the directions for tracing given in *Elements of Structural Drawing*, Part 1. Omit all construction lines and reference marks in tracing.

STRUCTURAL-STEEL MEMBERS

FABRICATION OF STEEL MEMBERS

22. Templets.—As soon as the detail drawings are approved, they are sent to the templet shop, where patterns, commonly known as templets, are constructed for the guidance of the men in the fabricating shop. These templets are usually made of white-pine boards $\frac{3}{4}$ or $\frac{7}{8}$ inch thick; for relatively small parts, durable cardboard $\frac{1}{8}$ inch thick is often used. On the templets are carefully located and cut the various notches and cuts which are to be made in the member; the holes to be drilled or punched in the member are then laid out accurately and their position indicated by boring holes of $\frac{1}{2}$-inch diameter in wooden templets and holes of $\frac{5}{8}$-inch diameter in cardboard templets.

One templet, or set of templets, is required for all members of a structure that are identical. Sometimes, by way of economy, one templet, or set of templets, is used for several members that are not exactly the same, the slight variations being indicated by means of notes and marks painted on the templets. On each templet should be painted the contract number, the drawing number, the mark of the piece to which it applies, the diameter of the holes in the member, and other information that would help identify the templet and facilitate the work of the men in the fabricating shop.

23. Fabrication.—The shapes shipped from the rolling mill to the fabricating shop are received and unloaded in the *stock yard*. For convenience in shipping, when several pieces

of the same length are required, the shapes are cut at the mill in multiple lengths—that is, lengths that are multiples of the length of one piece—the subsequent cutting or sawing into individual lengths being done in the stock yard. Some of the shapes become distorted in shipment while others curve somewhat on cooling after being rolled. Therefore, before they can be used in fabrication, they must be passed through a series of straightening rolls. After the piece has been properly straightened, the corresponding templet is laid on it and securely clamped in place. The correct length of the piece and the locations of all cuts in it are then marked off from the templet by means of a piece of soapstone. The positions of the holes that are to be drilled or punched in the member are then indicated by placing a center punch in each templet hole and striking it with a hammer, leaving a conical-shaped indentation in the steel. The soapstone lines are often rendered more distinct by a series of dents made with a center punch along their lengths. In order to effect economy, templets are often dispensed with and the work laid out directly on the steel shapes according to the structural drawings. After all work that is to be done on the member or piece is marked, the sizes of the holes that are to be drilled or punched are painted on it. In addition, each large piece has the contract number, the drawing number, and its identification mark painted on it in order to facilitate its identification when the assembly of the component parts of the structure or member is to be made.

After the shape has been properly marked off, it is first cut or sawed to exact size, if that has not been done previously at the mill or stock yard. All cuts and notches are then made in the pieces, and other work, such as rounding the corners or planing the edges, is completed. The holes are finally punched or drilled. When a shape is to be bent, it is usually bent before being marked off from the templet. Small pieces of short length are usually cut to exact size before they are marked off.

The various component parts of the members are then put together, or assembled, and held securely in position by means of temporary bolts, at least two bolts being required to hold

each piece in place. Before the pieces are bolted up, all surfaces in contact that will be inaccessible to painting after the pieces are permanently fastened together should be painted with one coat of approved paint or oil. The assembled members are then taken to the riveters, who drive the shop rivets by riveting machines or pneumatic hammers.

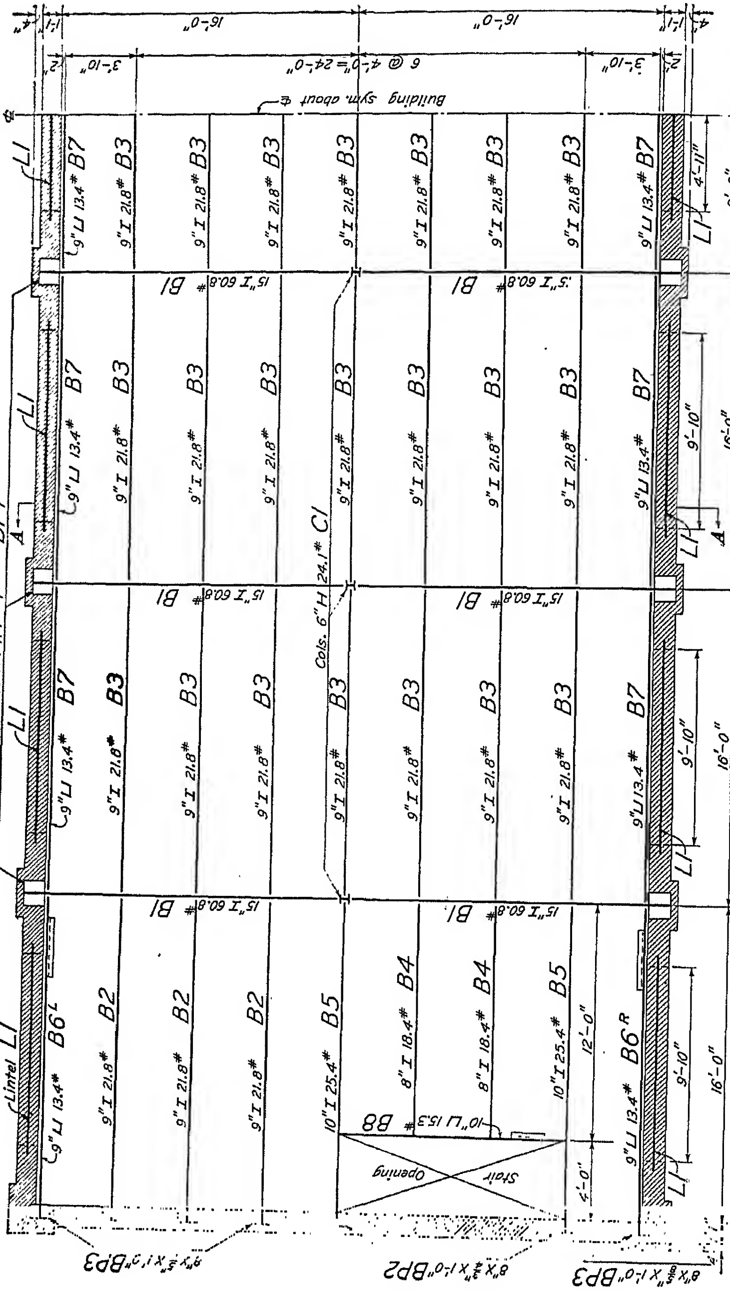
After the member has been completely riveted, it is carefully inspected by the shop inspector to make sure that all work was done properly, that all rivets are tight, and that provisions for connecting the member to the other members of the structure have been made. One or more coats of shop paint or oil of approved quality are then applied to the member, after which it is ready for shipment.

MEMBERS OF STEEL-FRAME BUILDINGS

24. Steel Frame.—In Fig. 10 is shown a perspective of part of the steel frame for a warehouse. The frame is composed of various members connected together by means of rivets or bolts to form a rigid structure. The members of the frame are constructed either of single shapes or of several shapes riveted together; they are named according to their construction or the function which they serve in the building.

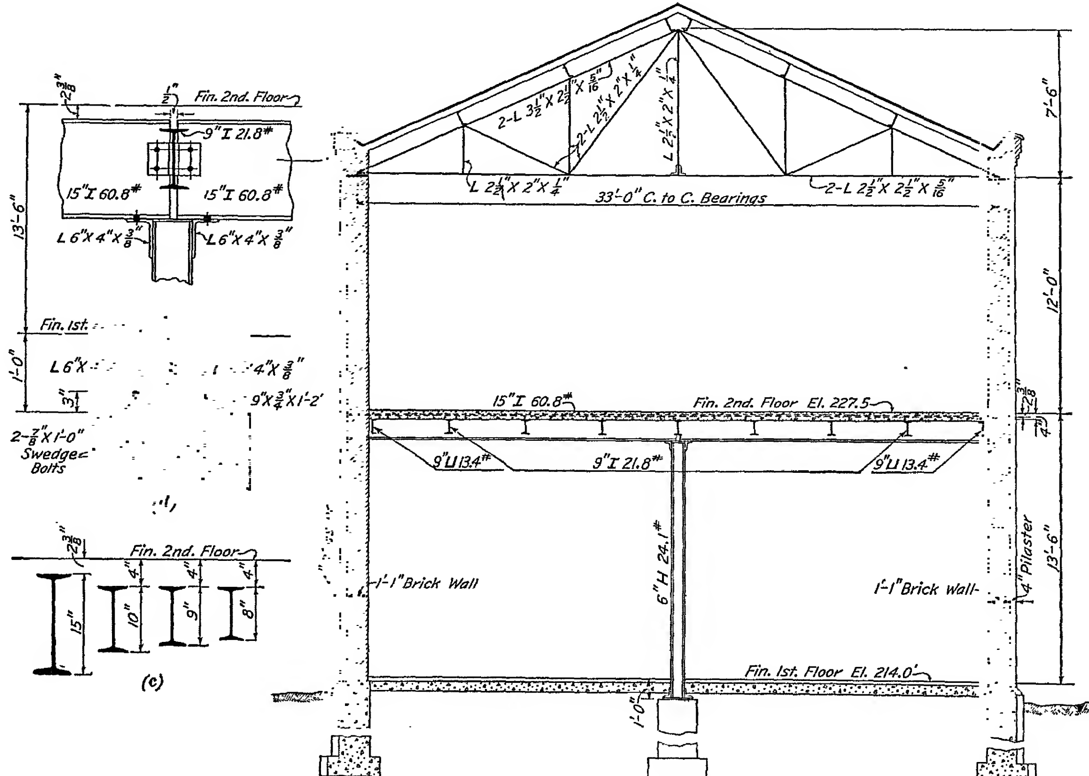
The horizontal members $B1^R$, $B1^L$, and *B2* in Fig. 10 are used to support the floor and whatever loads may come on it, and they are therefore known as *floorbeams*, or *beams*. The beams $B1^R$ and $B1^L$ frame into the horizontal members marked *G1* and *G2*, which are constructed by riveting together angles and plates and are known as *riveted girders*, or *girders*. The girders and the beams *B2* are connected to the upright members, known as *columns*, which are marked *C1*, *C2*, *C3*, and *C4*. In this frame the columns rest on *grillage footings* which are constructed of layers of **I** beams crossed at right angles. The lower layer of **I** beams rests on a concrete slab 12 or more inches thick.

Fig. 11 is a general drawing of the part of the steel frame shown in perspective in Fig. 10. In (*a*) is shown a plan view of the steelwork at the level of the first floor; in (*b*) is



Building sym. about ℄
16'-0"
6 @ 4'-0" = 24'-0"
3'-10"
4'-11"
8'-0"
9'-10"
16'-0"
56'-0"
12'-0"
4'-0"
9"⊔ 13.4# B7
9"I 21.8# B3
15"I 60.8# B1
Cols. 6"H 24.1# C1
16"x1"x1'-1" BP1
A
L1
Lintel L1
9"⊔ 13.4# B6L
9"⊔ 13.4# B6R
9"I 21.8# B2
10"I 25.4# B5
8"I 18.4# B4
10"⊔ 15.3# B8
Stair Opening
8"x5/8"x1'-0" BP3
8"x3/4"x1'-0" BP2

(a)
FIG. 12



Section AA
(b)

FIG. 12

shown a typical cross-section through the frame taken along the planes indicated by the line A–A in the plan view, and to the right of (*a*) is shown a section through the steelwork taken along the plane indicated by line B–B in the plan view. The beams and girders are respectively represented in the plan view by means of medium and heavy lines, which is the usual way of representing them on design drawings. In the sections, the various members are shown merely in outline, no effort being made to indicate the rivets.

25. Beams.—The beams of a steel-frame building, that are used to support the floor, are either **I** beams or channels. They usually frame into other beams, riveted girders or columns, or they rest on masonry walls.

In Fig. 12 is shown a drawing of the steelwork for a shop building: in (*a*) is a plan view of half of the second floor, and in (*b*) is a cross-section through the building taken along the plane indicated by line A–A in the plan view. The floor beams running lengthwise of the building consist of **I** beams and channels; they frame into 15-inch **I** beams running crosswise of the building and spaced 16 feet center to center, except at the ends where some of the floor beams rest on brick walls 13 inches thick. The 15-inch **I** beams are supported at the center of span by 6-inch **H** columns, and at the ends by the *pilasters* in the wall, which are formed by projecting the wall 4 inches in width for a length of 30 inches.

26. Riveted Girders.—Riveted girders usually consist of several steel shapes riveted together to form one member. Cross-sections of the common forms of riveted girders are illustrated in Fig. 13. The cross-section shown in (*a*) is composed of an **I** beam with *flange plates* riveted to its flanges. In (*b*) is shown an *I-beam box girder*, which is composed of two **I** beams connected by means of flange plates. In (*c*) is shown a *plate girder*, the most common type of riveted girder in use, which is composed of a plate, known as a *web plate*, and four angles called *flange angles*, riveted together so as to form an **I** shape. To increase the sectional area of the plate girder, one or more *cover plates* are riveted to each flange, as in (*d*). In

mill-building construction a channel is frequently riveted to the top flange of the girder in order to stiffen it laterally, as in (*e*). The cross-section illustrated in (*f*) is that of a *plate box girder*, composed of two web plates, four flange angles, and two or more cover plates. In order to stiffen the web of a riveted girder so as to prevent its buckling when the girder is heavily loaded, vertical angles, called *stiffener angles*, are riveted to the web and to the vertical legs of the flange angles, as the angles *a* in (*g*), where a part of the side elevation of a plate girder is shown.

Both **I** beams and riveted girders are generally used to resist transverse loads, the girders being used for heavier

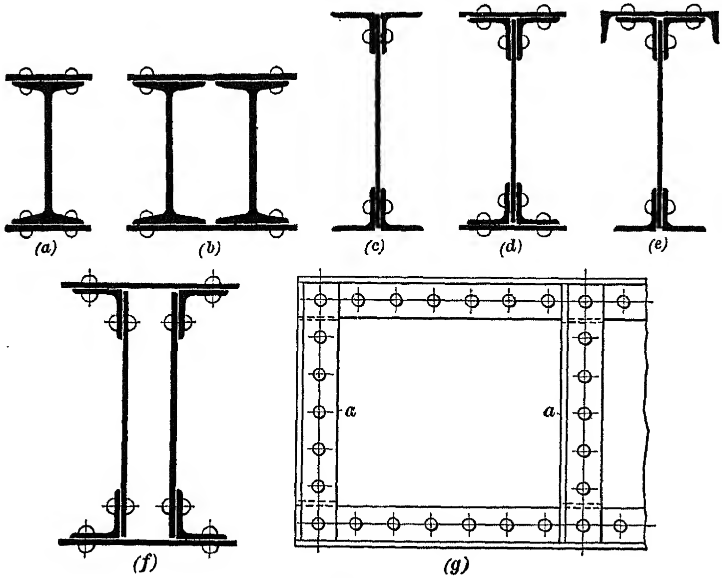


FIG. 13

loads and longer spans. Other conditions may often make it necessary to use a girder instead of an **I** beam. However, when no special conditions demand it, members consisting of single rolled shapes should always be used in preference to members composed of two or more shapes riveted together, because they are more economical and easier to construct.

In structures that carry heavy loads, riveted girders are employed to support either the floor beams of the structure, as girders *G2* in Fig. 11 (*a*); the floor beams of the structure and the brick wall over windows or other openings in the wall, as girders *G1*; or merely the brick wall over openings, as girders *G3*. In structures that carry light loads, these functions are well served by I beams or other rolled shapes.

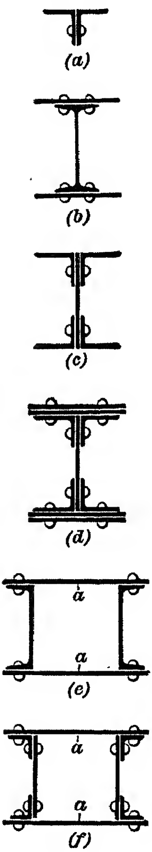


FIG. 14

27. Columns.—The steel columns that support the girders and beams usually extend from the footings below the lowest floor to the roof. In some structures they extend only to the top floor, as in Fig. 12. Columns are constructed of several shapes riveted together or of a single shape such as an angle, **H** section, **I** beam or channel. Of the rolled sections, the **H** section is most widely used because it is particularly suited to column construction. Cross-sections of the more common riveted columns are shown in Fig. 14. In (*a*) is shown a section formed of two angles riveted together, while in (*b*) is shown a section composed of an **I** beam and two cover plates. The cross-section shown in (*c*) is of a *plate-and-angle column*, the most popular form of riveted column, which is composed of a web plate and four flange angles; frequently, one or more cover plates are riveted to each flange of the column to increase its area and stiffness, as in (*d*). The column shown in (*e*) is composed of two channels and two cover plates, and that shown in (*f*) is composed of four plates and four angles.

The web plate in the column shown in (*c*) and the cover plates in the columns shown in (*e*) and (*f*) are sometimes omitted and the two halves of the column are connected by means of steel bars, known as *lacing*, or *lattice*, *bars*. In (*a*) and (*b*) in Fig. 15 are illustrated alternative part side elevations showing

different methods of constructing the column shown in section in Fig. 14 (*e*), the two channels being connected by means of cover plates in (*a*) and by means of lacing bars *l* in (*b*). Similarly, in (*c*) and (*d*) in Fig. 15 are illustrated alternative part side elevations for the column shown in section in Fig. 14 (*f*), cover plates being used in (*c*) and lacing bars *l* in (*d*). The lacing shown in (*b*) is known as *single lacing*, while that shown in (*d*) is called *double lacing*, single lacing being used when the distance *d* between the rivet lines is less than 15 inches and double lacing when it is greater than 15 inches. The inclina-

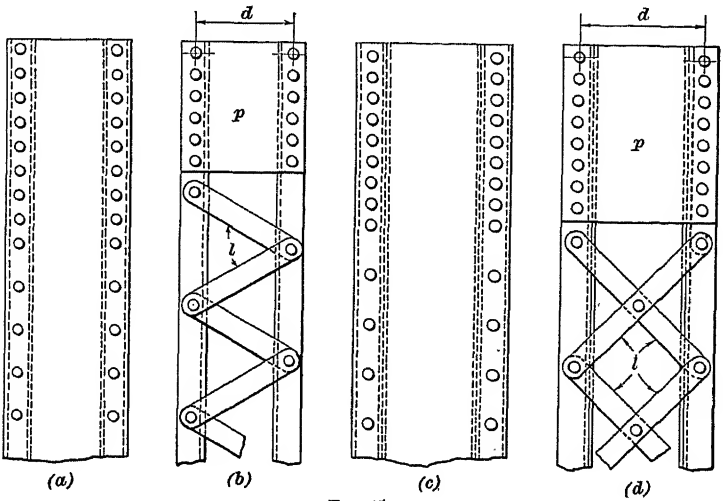


FIG. 15

tion of single lacing bars with the axis of the column is generally about 60 degrees, and of double lacing bars about 45 degrees. *Tie plates* *p* are used at the ends of each system of lacing; that is, at the ends of the member or where the lacing must be omitted for structural reasons.

28. Trusses.—When it is necessary to support the loads of a structure over a long distance, as the roof of a building between the outside walls, *trusses* are advantageously employed. These trusses are usually constructed by connecting together several members, which are composed of one or more

shapes, in such a manner as to form a series of triangles. Thus, the roof of the building shown in Fig. 12 (*b*) is carried by the steel trusses, which are composed of several members, each member consisting either of one angle or of two angles riveted together, as in Fig. 14 (*a*).

RIVETS IN STEEL MEMBERS

29. Importance of Rivets.— As previously explained, most steel structures are composed of steel shapes riveted together. The rivets that connect the steel shapes to form members or structures constitute important links upon whose strength frequently depends the safety of the structure. Too much stress cannot, therefore, be laid on the importance of so designing riveted connections that a sufficient number of rivets are provided and their spacing is properly arranged. The spacing, and often the number, of rivets in connections is determined by the detailer.

30. Rivet Spacing.—Rivets are usually spaced along lines called *rivet lines* or *gauge lines*. The distance from center to center of rivets along rivet lines is known as the *rivet pitch*, or *pitch*. In Fig. 16, *r* is a rivet line and *p* the rivet pitch.

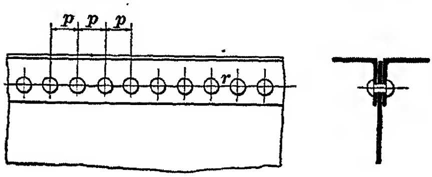


Fig. 16

Good practice demands that the spacing of rivets, or the rivet pitch, should be controlled by minimum and maximum limits. If the rivets are spaced too closely, the material between rivets is likely to fracture or fail. On the other hand, if the rivets are spaced too far apart, their effectiveness as connecting links may be greatly impaired.

The spacing of rivets should not be less than three times the diameter of the rivet. Thus, if the rivet is $\frac{7}{8}$ inch in diameter, the minimum spacing should be $3 \times \frac{7}{8}$ inch $= 2\frac{5}{8}$ inches. The minimum spacing commonly used in practice differs somewhat from three diameters, as is evident from Table V,

where the minimum pitch based on 3 diameters is given in the first line and the minimum pitch commonly used in practice is given in the second line.

The maximum spacing of rivets is governed not only by the diameter of the rivets but also by their function. The general practice is to space rivets that connect the component parts of riveted girders and columns not more than 6 inches apart when the diameter of the rivet is $\frac{3}{4}$, $\frac{7}{8}$, 1 inch or $1\frac{1}{8}$ inches; not more than $4\frac{1}{2}$ inches apart when the diameter of the rivet is $\frac{5}{8}$ inch, and not more than 4 inches apart when the diameter of the rivet is $\frac{3}{8}$ or $\frac{1}{2}$ inch; provided, however, that the pitch does not exceed 16 times the thickness of the thinnest outside metal connected by the rivets. For example, if the leg of either angle in Fig. 16 is $\frac{5}{16}$ inch thick, the spacing of the rivets whose diameter is $\frac{3}{4}$ inch or more should not exceed $16\times\frac{5}{16}=5$ inches. In a member that carries compressive stress, it is good practice to make the spacing of the rivets that connect the component parts of the member not more than 4 diameters of the rivet for a distance equal to $1\frac{1}{2}$ times the width of the member from the ends and also opposite the connections of the member to other important members; the allowable maximum spacing may be used in the other parts of the member.

In light members, rivets that do not carry much stress are usually spaced farther apart than the distances just specified. Thus, when a member of a truss is composed of two angles riveted together at intervals, the rivets, which are commonly known as *stitch rivets*, are usually spaced about 2 feet 6 inches apart if the member carries a tensile stress, and about 1 foot 6 inches apart if the member carries a compressive stress.

31. Edge Distances.—In order to avoid the danger of their pulling out, rivets should not be placed too near the edge of the material through which they pass. The perpendicular distance from the center of a rivet to the edge of any structural shape through which it passes, is known as the *edge distance*. The recommended practice is to allow an edge distance not less than 2 diameters of the rivet when plates are connected by

means of rivets. The general practice, however, is to use an edge distance slightly less than 2 diameters, as is evident from Table V where the minimum edge distance based on 2 diameters is given in the fourth line and the usual minimum edge distance used in practice is given in the fifth line. In extreme cases, such as difficult connections that cannot be otherwise arranged, an extreme edge distance of $1\frac{1}{2}$ diameters, given in the last line in Table V, may be used.

The minimum edge distances here specified apply to plates with sheared edges. Edge distances for rolled edges, such as in flanges of rolled shapes, may be made somewhat less.

The edge distance should not exceed 5 inches or 8 times the thickness of the thinnest outside metal connected by the rivets.

The edge distances, as well as the minimum and maximum spacing of rivets, are frequently governed by the *specifications*, which constitute a part of the written contract between the purchaser of the steel work and the fabricating company. The specifications define the workmanship and quality of materials desired. They are generally drawn up by the customer's engineers.

32. Standard Gauges.—In structural-steel work, the term *gauge* means the distance between rivet lines in the flanges of **I** beams, **H** beams, or tees, as *g* in Table IV; the distance between rivet lines in legs of angles; the distance from the back of the web of a channel or zee to the rivet lines in the flange, as *g* in Table III; the distance from the back of an angle to the rivet line, or the first rivet line when two are used in the leg of the angle. As a result of long experience, standard gauges for the various shapes have been adopted and are in common use. The standard gauges for **I** beams are given in the sixth column in Table IV, and the standard gauges for channels in the sixth column in Table III. Unless economy in construction warrants a change, these standard gauges should always be employed.

In Table VI are given standard gauges for angles, and the maximum-size rivets that may be used in the legs of the angles. As will be observed in the table, either one or two gauge lines

may be used in the 8-, 7-, 6-, 5-, and $4\frac{1}{2}$-inch legs, and only one gauge line in legs of less width. Thus, if the leg of an angle

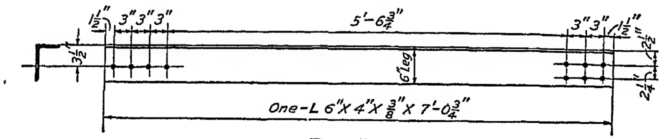


FIG. 17

is 6 inches wide, either one $3\frac{1}{2}$-inch gauge may be employed, as at the left-hand end of the angle detailed in Fig. 17, or two gauges may be used, one $2\frac{1}{2}$ inches and one $2\frac{1}{4}$ inches, as at the right-hand end of the angle shown. The gauges of angles are often changed to suit the needs of construction, as will be explained later.

33. Practical Considerations.—Where two gauge lines are used in the leg of an angle, it is frequently better to stagger the rivets, as in Fig. 18, so that the center lines of the rivets in one line are spaced midway between the center lines of the rivets in the other line. This is done mainly to prevent excessive reduction of the gross area of the angle by rivet holes in the cross-section through the rivet holes. When the rivets on two adjacent gauge lines are *staggered*, or *alternated*, as in Fig. 18, the rivet pitch p is the distance from the center of a rivet on one line to the center of the nearest rivet on the other line, measured parallel to the gauge lines. The pitch of staggered rivets may be closer than the minimum spacing specified in Art. **30**, but the distance m between the center of a rivet on one gauge line and the center of the next rivet on the other gauge line, measured along the line joining their centers, should be not less than the specified minimum spacing.

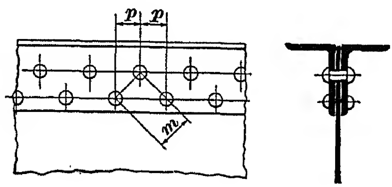


FIG. 18

Rivets should always be so located that no great difficulty will be encountered in driving them. Most rivets are driven by riveting machines, and sufficient clearance should be provided between the rivet

heads in a member and any projecting parts, so that the dies which form the heads can be held in place without much trouble. The minimum clearances commonly used in practice are as given in the first line in Table VII while the extreme minimum clearances are given in the second line. Where sufficient clearance *c* cannot be provided between the heads of the rivets in one leg of an angle and the center line of the rivets in the other leg, the rivets in the two legs should be staggered, as in Fig. 19.

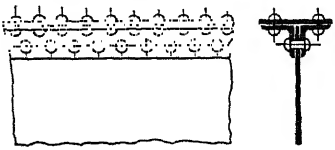


FIG. 19

DETAILS OF STRUCTURAL-STEEL MEMBERS

DETAILS OF BEAMS

METHODS OF DETAILING

34. Conventional Methods of Representation.—In detailing steel beams certain conventional methods are followed which reduce greatly the time required for making the drawings. For instance, in drawing the views of a beam, it is customary to show its depth and width and its details to some suitable

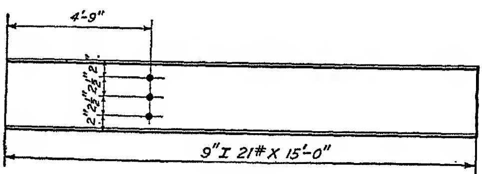


FIG. 20

scale, such as $\frac{3}{4}$ inch = 1 foot, or 1 inch = 1 foot, but its length is not shown to scale; any convenient length is shown, and the distances between details along the beam are laid off approximately in their relative positions. Thus, if the total length of the beam is 15 feet, as in Fig. 20, and a line of holes in its

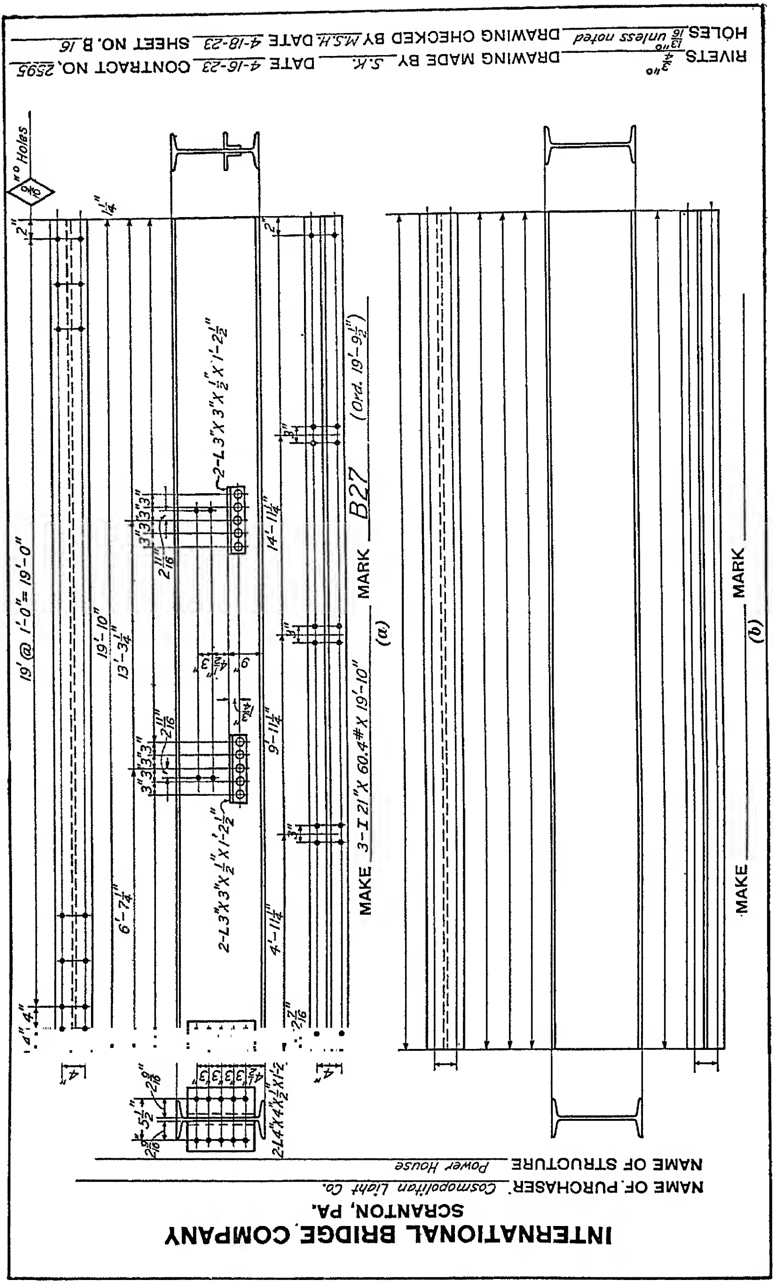

INTERNATIONAL BRIDGE COMPANY
SCRANTON, PA.
NAME OF PURCHASER Cosmopolitan Light Co.
NAME OF STRUCTURE Power House
RIVETS 3/4" DRAWING MADE BY S.K. DATE 4-16-23 CONTRACT NO. 2595
HOLES 13/16" unless noted DRAWING CHECKED BY M.S.H. DATE 4-18-23 SHEET NO. B 16
MAKE 3-I 21"X 60.4#X 19'-10" MARK B27 (Ord. 19'-9 1/2")
(a)
19' @ 1'-0" = 19'-0"
19'-10"
13'-3 1/4"
6'-7 1/4"
14'-11 1/4"
9'-11 1/4"
4'-11 1/4"
2-L 3"X 3"X 1/2"X 1'-2 1/2"
2-L 4"X 4"X 1/2"X 1'-2
MAKE
MARK
(b)

Fig. 22

web is to be located 4 feet 9 inches from its left end, then whatever total length of beam is shown, the line of holes would be located at a distance of approximately one-third of that length from the left end of the beam. All standard dimensions that apply to the size of the shape are omitted and only those dimensions necessary for fabricating the members are shown.

35. Printed Beam Sheets.—In order to save time in making detail drawings of beams, some companies supply their draftsmen with printed beam sheets, such as are illustrated in Figs. 21 and 22. The sheet illustrated in Fig. 21 applies to I beams of relatively simple construction; it usually contains three or four sketches, showing elevations and end views of I beams with dimension lines, and is printed on tracing cloth or transparent paper. The sheet illustrated in Fig. 22 applies to more complex construction than that illustrated in Fig. 21, since besides the elevations and end views, there are also shown top views and bottom-sectional views. In Fig. 21 the sketches in (*a*), (*b*) and (*c*) are filled in, while the sketch in (*d*) is left blank. Likewise, in Fig. 22 the sketch in (*a*) is filled in and the sketch in (*b*) is left blank.

When printed beam sheets are employed, no dimension of the beam is shown to scale, since the same side elevation is used for any depth or length of beam. Nevertheless, for the sake of good appearance, the various details of the beam should be plotted roughly to about the same scale that corresponds to the depth of the beam, and the various details should be spaced along the length of the beam so that they are approximately in their relative positions. However, the main object in beam detailing is to have the various dimensions clearly indicated.

It will be noticed that above the elevations of the beams there are three dimension lines, while below them there is only one. The use to which these lines may be put is arbitrary, except that one of them should indicate the total length of the beam. In some cases, one or more of the dimension lines are superfluous, as in (*a*) and (*c*) in Fig. 21.

For beams of complex construction, sheets with printed beam sketches cannot be conveniently used. Such beams are

usually detailed on sheets which are similar to those illustrated in Figs. 21 and 22, except that no beam sketches are printed on them. In some offices all beam detailing is done on such blank sheets.

CONNECTIONS OF BEAMS

36. Connections of Beams to Beams.—The most common method of connecting one beam to another is by means of small angles riveted to the webs of the beams. Such a connection is

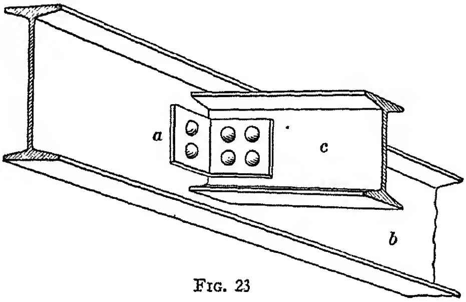


Fig. 23

shown in perspective in Fig. 23, where the angle *a* connects the beams *b* and *c*. Details of the connection are shown in Fig. 24, where an elevation of part of beam *c* is shown in (*a*), and an elevation of part of beam *b* in (*b*). The connection angles *a* are connected to the web of beam *c* by means of shop rivets and to the web of beam *b* by means of field rivets. Such simple connections are so common in steel construction that *standard*

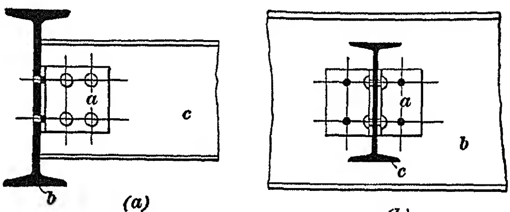
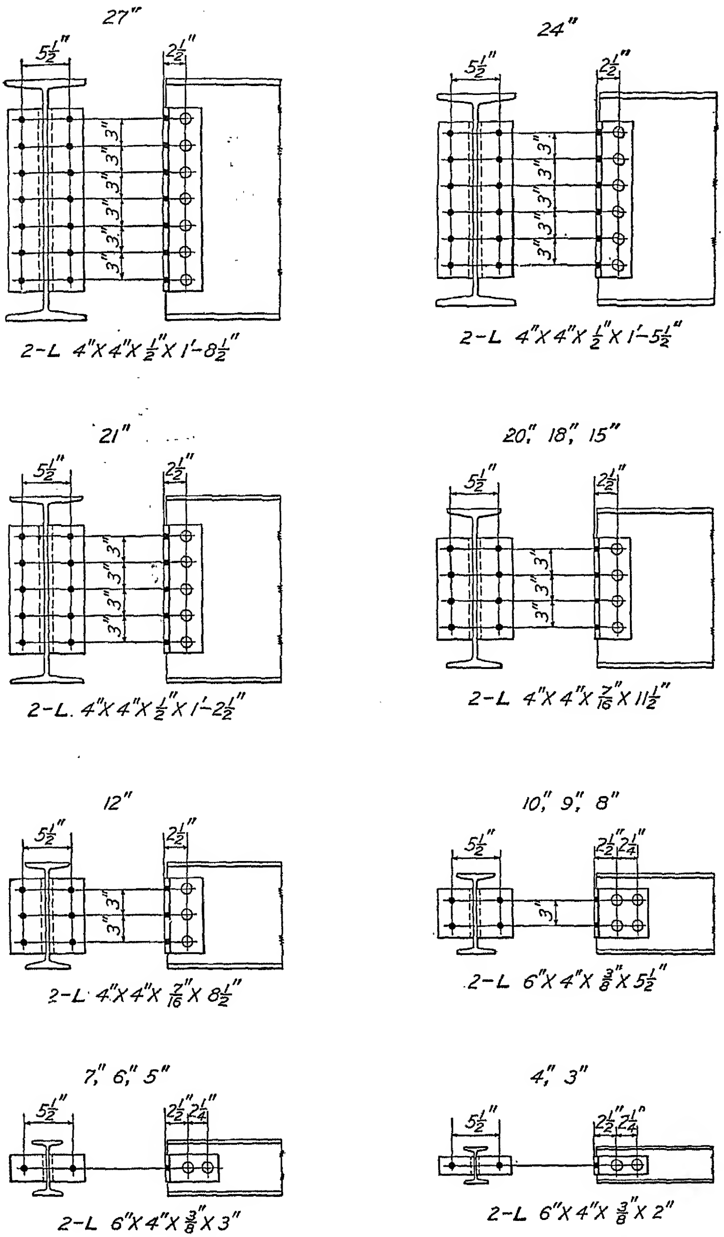


Fig. 24

connection angles are used by the various steel companies. The standard connections were designed so that, for the usual spans of beams, the rivets can safely resist the maximum load



Rivets and Bolts ¾" Diameter

FIG. 25

that the beam can carry without developing excessive bending stresses. However, these standard connections may not be sufficiently strong for beams of short span that are heavily loaded, in which cases special connections are required.

37. The standard connection angles shown in Fig. 25 are those given in the *Carnegie Pocket Companion* of the Carnegie Steel Company, Pittsburgh, Pa. Other connection angles are used by some of the other steel companies. However, since the standard connection angles of the Carnegie Steel Company are most widely used in practice, they have been adopted for use here. These connection angles were intended mainly for I beams; they are also employed for the connection of channels of the same depth, except that the connection angles for I beams of 12-inch depth are also used for channels of 13-inch depth.

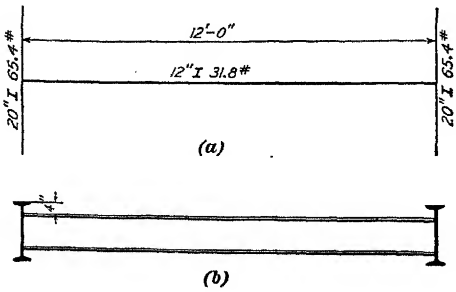


FIG. 26

In the average structural-steel shop, the standard connection angles for the beams that are commonly used are manufactured in large quantities; they are usually carried in stock, and require no additional templets when employed in the fabrication of beams. In detailing beams, the draftsman should endeavor to use standard connection angles wherever possible, because he thus lessens the work in the templet and fabricating shops.

In Fig. 26, in the plan view (*a*) and the elevation (*b*), is shown a diagrammatic representation of a 12-inch 31.8-pound **I** beam (written 12″ **I** 31.8 lb.) framing between two 20-inch 65.4-pound **I** beams. A detail drawing of the 12-inch 31.8-pound **I** beam is shown in Fig. 27. The connections of the beam are made by means of standard connection angles, which are shown in complete detail. In many offices, however, it is customary not to detail standard connection angles, but merely

to give the distance of the first line of open holes for field rivets from either the top or the bottom of the beam. These angles

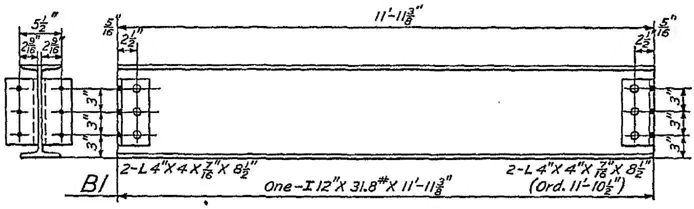


FIG. 27

are usually represented as at the left end of the beam, as shown in Fig. 28.

38. It frequently happens in structural work that two connection angles cannot be used, on account of difficulty in making the connection or because of interference with other

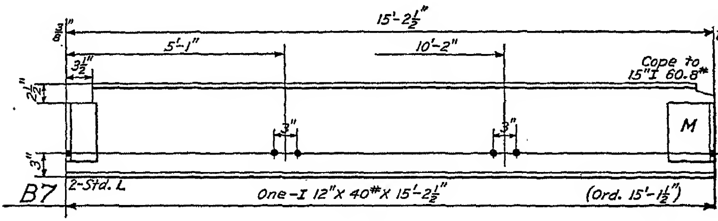


FIG. 28

connections. Such a condition is illustrated in Fig. 29, where two **I** beams frame into a third **I** beam. If two connection angles were used for each of the two beams, the angles between the beams would overlap. Besides, it would be impossible to drive rivets between the two beams. One-angle connections

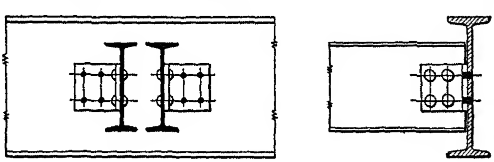


FIG. 29

are therefore used. Such a connection is usually made by means of a $6'' \times 6'' \times \frac{3}{8}''$ angle which contains sufficient field

rivets to develop the strength of a standard connection with two angles. In some structural offices these single connection angles are considered standard and hence are not detailed on the drawing. Thus, in the American Bridge Company offices such connection angles are marked by a letter *M*, as at the right end of the beam in Fig. 28, and the location of the first line of open holes in these angles is the only dimension given. When one-angle connections are used, care should be taken to indicate clearly on which side of the beam the angle is connected.

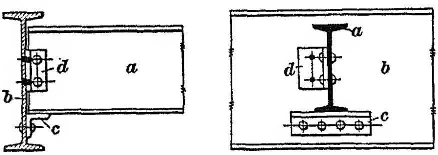


FIG. 30

In detailing structural-steel beams it is not always possible to use standard connection angles. All connection angles that differ in any way from the standard connection angles should be completely detailed.

39. A typical connection of one beam to another, which is sometimes used in office-building construction, is that shown in Fig. 30. The beam *a* rests on a horizontal *seat angle c* which is riveted to the beam *b*, sufficient rivets being provided in the seat angle to carry safely the entire load from beam *a*. The beam *a* is kept in place by means of the small *clip angle d* which is riveted or bolted to the web of beam *a* and is usually bolted to the web of beam *b*.

When one beam rests on top of another, as in Fig. 31, the connection is made by means of rivets or bolts which connect the top flange of the lower beam to the bottom flange of the upper beam. Such rivets or bolts do not carry stress but merely hold the upper beam in place.

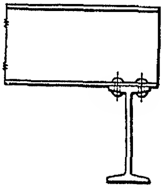


FIG. 31

40. Connections of Beams to Columns. Connections of beams to columns are made either by framing the beams into the columns or by resting them on top of the columns. When beams frame into columns they may be connected by means of two

connection angles, either standard or special. Thus, in Fig. 32, the beam *a* is connected to column *b* by means of two con-

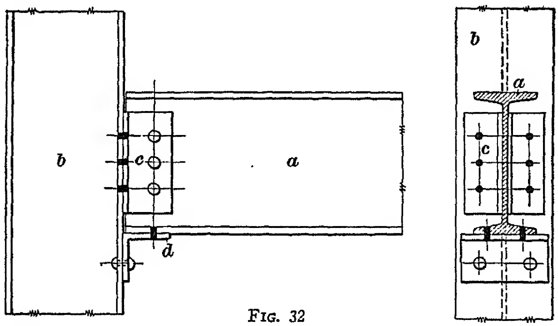


FIG. 32

nection angles *c*. In such connections, a horizontal seat angle *d* is often provided to facilitate erection, the rivets in the connection angles being relied on to transmit the load from the beam. The lower flange of the beam is usually bolted to the seat angle, which is riveted to the column.

In office-building construction, where speed in erection is an important factor, a commonly used method of connecting a beam to a column is to support the beam on a horizontal seat angle, which is riveted to the column, and to bolt the bottom flange of the beam to that seat angle, as in Fig. 33. The top of the beam is held in place by means of a small *top angle*, which is riveted or bolted to the column and is bolted to the top flange of the beam. The rivets in the seat angle only are relied on to transmit the load from the beam. When the load carried by the beam is large, the beam is supported on a *bracket*, as in Fig. 34. This bracket is composed of a horizontal seat angle *a*, one or two vertical *stiffener angles b* riveted to the seat angle and to the column, and a *filler plate c* which fills the space between the stiffener angles and the web of the column below the vertical leg of the seat

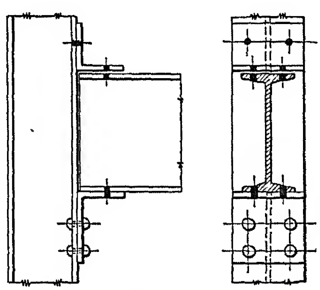


FIG. 33

angle. The function of the stiffener angles is to stiffen the horizontal leg of the seat angle and to help transmit the load from the beam to the column.

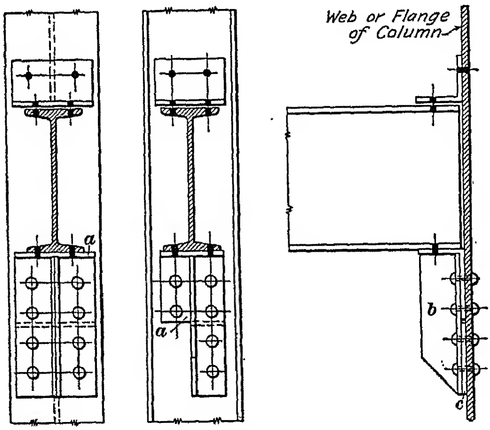


FIG. 34

When the beam rests on top of the column, the connection is made in a manner similar to that shown in Fig. 35, the lower flange of the beam being riveted to the *cap angles c* of the column.

41. Connections of Beams to Girders.—Light beams are usually connected to girders by means of one or two connection angles in the manner shown in Figs. 24 and 29 for the connections of beams to beams. In office-building construction, seat angles are often riveted to the girders and the connection made as shown in Fig. 30. A type of connection frequently used in office building construction is that shown in Fig. 36 where the beam rests on a seat angle *a* provided with one or two

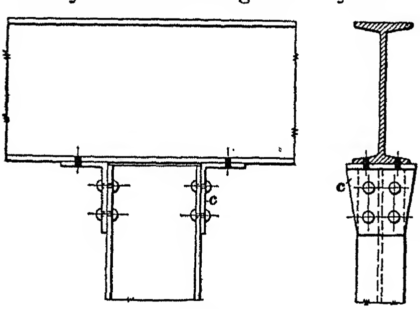


FIG. 35

stiffener angles *b* and is bolted to a vertical angle *c*. Another method of connecting a beam to a girder is shown in Fig. 37; the web of each beam is connected to the stiffener angle of the girder by means of a plate which sometimes extends below the bottom of the beam and necessitates cutting the flange of the beam, as shown. When the beam rests on top of a girder, its lower flange is riveted to the top flange of the girder.

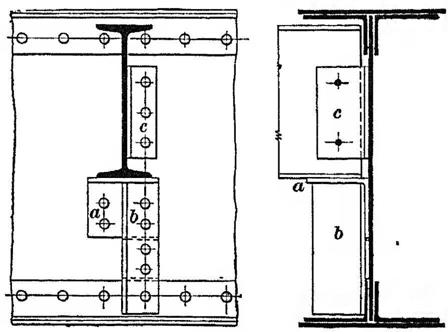


FIG. 36

42. Beams Supported by Masonry Walls.—In building construction, beams are frequently supported by masonry walls, as in the building shown in Fig. 12. In order that the load from the beam may be distributed over a sufficient area of masonry so as not to exceed the allowable unit bearing on the masonry, steel *bearing plates* are generally put on the masonry wall and the

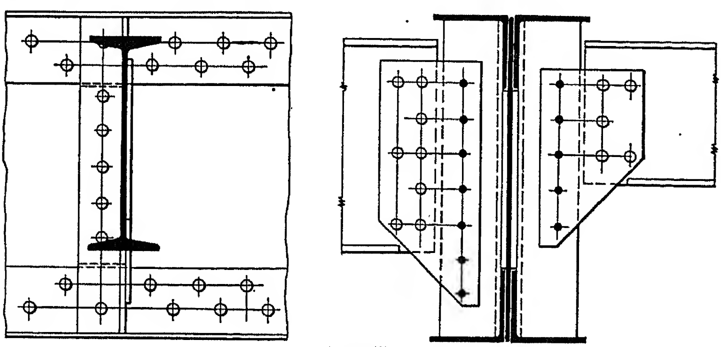


FIG. 37

beams are placed on them. The area and thickness of such bearing plates required to transmit properly the load from the beams may be computed by the principles of design. Under ordinary conditions, the standard bearing plates given in the

last column in Tables III and IV are employed. Thus, for an 18″ I 90 lb., a 16″×1″×1′4″ bearing plate would be employed, while for a 15″ I 42.9 lb. a 12″×1″×1′ 4″ bearing plate is required. The bearing plates are generally placed with their longer dimensions along the wall, as in Fig. 38, and the distance the beam projects into the wall is equal to the shorter dimension of the bearing plate.

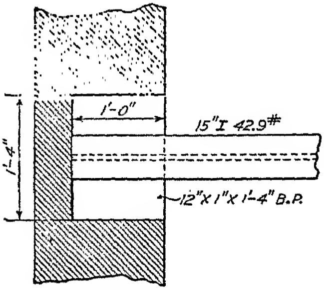
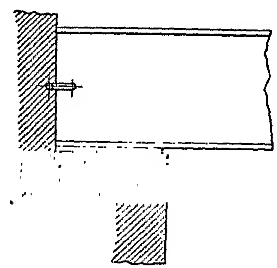


Fig. 38

The beams are not attached to the bearing plates, but are kept in place by means of anchors which are imbedded in the masonry. The usual method of anchoring the beam to the masonry is by means of a Government anchor, which is a bent rod of $\frac{3}{4}$-inch diameter, as in Fig. 39; the Government anchor is passed through a hole in the web generally located about 2 inches from the end and in the middle of the beam. Another method of anchoring the beam to the masonry is by means of two small angles which are bolted to the web, as in Fig. 40.



43. Erection Clearance. When the length of a beam with connection angles at both ends is given on a drawing, the distance from back to back of the connection angles is always implied. As will be explained later, this distance is greater than the actual length of the beam. The distance from back to back of angles is usually made less than the clear distance between the surfaces to which they are connected, in order to provide for clearance which is necessary in erection. The *erection clear-*

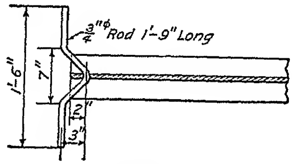


Fig. 39

ance is usually $\frac{1}{16}$ inch at each end of the beam. In order to facilitate checking the drawings, it is customary to indicate in a convenient place at each end of the beam, preferably at each end of the over-all dimension line, the distance from the backs of the connection angles to the *working line* of the member to which they connect. In columns, girders, and **I** beams, the working line is the center line of the member. In channels framed with their webs vertical, it is often found more convenient to use the back of the channel as the working line.

In Fig. 26 the working line of each 20″ **I** 65.4 lb. is its center line, and the distance between these working lines is 12 feet 0 inches. Since according to Table IV one-half of the web thickness for a 20″ **I** 65.4 lb. is $\frac{1}{4}$ inch, allowing $\frac{1}{16}$ inch for clearance, the distance from the back of the connection angles of the 12″ **I** 31.8 lb. to the working line of the member to which they connect is $\frac{1}{4}$ in. $+\frac{1}{16}$ in. $=\frac{5}{16}$ inch, which distance is marked at each end of the over-all dimension line in Fig. 27. The length of the beam is therefore 12 ft. 0 in. $-2\times\frac{5}{16}$ in. $=11$ feet $11\frac{3}{8}$ inches. The distance from the backs of the connection angles to the center lines of the webs of the beams, or the backs of channels, to which they connect may be found in Tables III and IV under the heading *Distance* and under the subheading *h*.

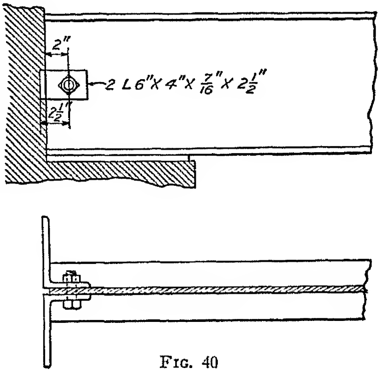


FIG. 40

When a beam frames into another beam at one end and rests on a masonry wall at the other end, no erection clearance need be allowed.

44. Ordered Lengths.—The lengths of **I** beams and channels, as ordered from the mills, seldom agree with the nominal lengths of the beams shown on the drawings. As previously stated, the beams are sawed at the mills when they are still

hot, and hence in the usual cases great precision cannot be expected. It is good practice to order beams in such lengths that they can be used when cut either $\frac{3}{8}$ inch longer or shorter than the required length. In ordering beams it is customary to give the lengths to the nearest $\frac{1}{2}$ inch. The ordered lengths should be about $\frac{3}{4}$ inch shorter than the distance back to back of connection angles. In detailing beams, the ordered length is often given in parenthesis immediately after the nominal length; thus, in Fig. 27, the nominal length of the beam is 11 feet $11\frac{3}{8}$ inches and the ordered length is 11 feet $10\frac{1}{2}$ inches; likewise, in Fig. 28, the nominal length is 15 feet $2\frac{1}{2}$ inches, while the ordered length is 15 feet $1\frac{1}{2}$ inches. However, it is not necessary to show on the drawing that the connection angles project beyond the ends of the beam, because it is more expedient to draw the backs of the angles in the same line with the ends of the beams, as in Figs. 27 and 28.

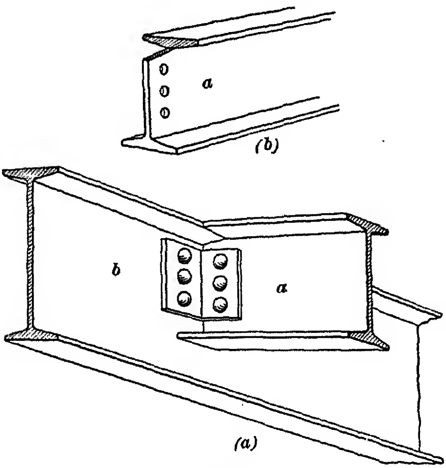
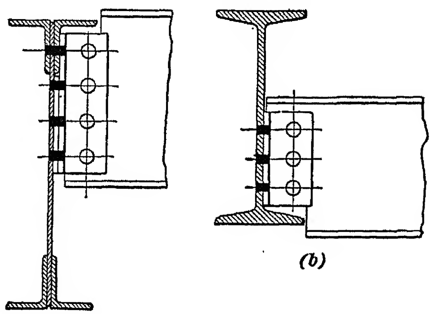


FIG. 41

45. Coping.—Construction conditions often make it necessary to frame one beam into another so that their tops or bottoms are flush, as beams *a* and *b* in Fig. 41 (*a*). It is then necessary to cut away part of the flange of beam *a*, as in (*b*), so that it clears the flange of beam *b* into which it frames. This process is known as *coping*, and beams so cut are said to be *coped*. In detailing beams it is customary to indicate coping either by blackening the coped portion, as in Fig. 21 (*a*), or by leaving it blank, as at the right end of the beam in Fig. 28. The dimensions of the cut are not given because the coping is

done by a standard process. It is merely necessary to state the size of the beam for which the coping is to be provided; thus, in Fig. 28, the indicated coping and the note, *Cope to 15″* I *60.8 #*, supply all the necessary information.

46. Miscellaneous Cuts.—When a beam frames into another beam or girder so that the top of the beam is above the top of the other beam or girder, it is necessary to cut part of the flange and web, as in Fig. 42 (*a*), to avoid interference; similarly, when the bottom of the beam is below the bottom of the beam or girder into which it frames, the cut is made as in (*b*). In detailing such beams, the cut portion may be blackened, as at the right end of the beam in Fig. 21 (*c*), or left blank, as at the left end of the beam in Fig. 28, and should be properly dimensioned.



(*a*) (*b*)

FIG. 42

In order to clear other surfaces, it is often found necessary to cut part of the flanges of the beams, as at the left end of the beam shown in Fig. 43 (*a*). The length of such cuts is indicated by a dimension, and the cut portion is blackened or left blank. A note should be given specifying the side on which the cut is to be made and stating whether or not the cut flange is to be chipped off flush with the web. At the left end of the beam shown in Fig. 43 (*b*), it is more convenient to indicate the cut portion of the flange by leaving it blank, while at the left end of the beam in Fig. 21 (*b*), the cut portion of the flange is best shown blackened. Sometimes, the cutting of the flanges may be avoided by simply setting the connection angles so that their backs project sufficiently far beyond the end of the beam, as at the left end of the beam shown in Fig. 21 (*c*) and at the right end of the beam shown in Fig. 43 (*b*), where the beams are set back 1 inch.

When a beam is supported on top of a girder or another beam so that the bottom of the beam is below the top of the girder or beam on which it rests, it is often best to cut the flange and web of the beam and to rivet one or two horizontal angles to the web, as at the right end of the beam shown in Fig. 43 (*a*); the connection may then be made by riveting or bolting the horizontal angles to the supporting beam or girder. The horizontal angles should project beyond the cut, as shown. In

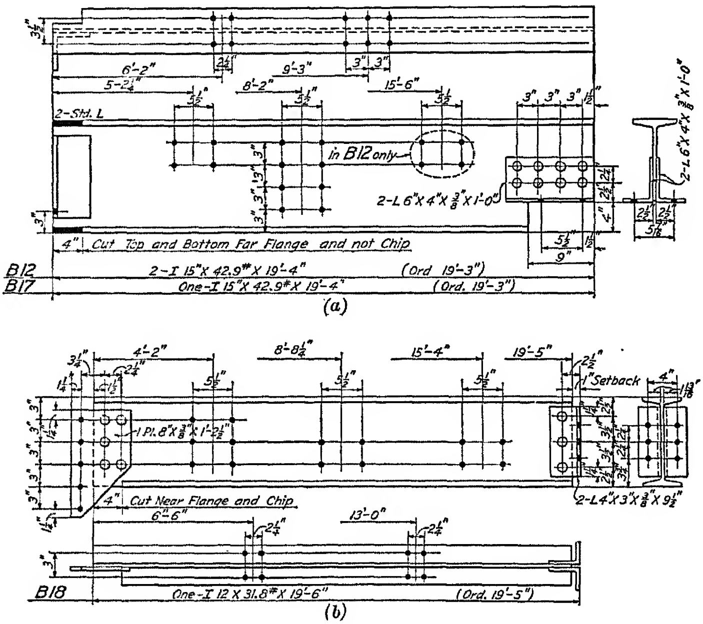


FIG. 43

such connections care should be taken not to cut too much of the web, in order that the ability of the beam to resist the reactions at its ends may not be impaired.

47. Location of Holes in Webs and Flanges of Beams. According to the best modern practice, the groups of holes in the webs and flanges of beams for the connection of other members should be located horizontally by dimensions from the left end of the beam to the center of each group. This is

done for the convenience of the men in the shop in order to enable them to locate the centers of the groups of holes with one stretch of the measuring tape. All these dimensions may be placed in one line in the manner shown in Figs. 21 (*a*), 22 (*a*), 28, and 43; the distance from the left end of the beam to the first group of holes is shown in the usual manner, but the distances to the remaining groups are shown by means of short lines with single arrowheads and figures placed above those lines. Such dimensions are known as *extension dimensions*.

When there are an even number of vertical rows of holes it is not necessary to indicate the distance from the rows to the center line of the group, it being assumed that the rows are placed symmetrically about the center line. The vertical location of the holes in the web is usually given from either the top or the bottom of the beam, preferably from the bottom, as shown in Figs. 21, 28, and 43.

The maximum size of rivet that may be driven in the flanges of **I** beams and channels is given in the next to the last column in Tables III and IV.

MISCELLANEOUS DETAILS

48. Tie Rods.—In order to strengthen the floorbeams against sidewise deflection, it is customary to provide *tie rods*, as *r* in Fig. 11, which are $\frac{5}{8}$-inch, $\frac{3}{4}$-inch or $\frac{7}{8}$-inch rods threaded at both ends; the rods are passed through the webs of two adjacent beams and are provided with nuts at each end, as shown in Fig. 44, in elevation in (*a*) and in plan in (*b*).

The holes for the rods are located in pairs by extension dimensions from the left end of the beam to the line midway between the two holes, as in Fig. 28. The distance between the two holes is usually 3 inches. The vertical location of the holes depends upon the floor construction. When the beams support arches it is customary to place the tie rods near the bottom flanges; otherwise, they are placed near the top flanges. The number and size of tie rods are usually specified by the designer.

49. Beam Girders.—Riveted beam girders are constructed by riveting flange plates to the flanges of an I beam, as in Fig. 13 (*a*); by riveting a channel to an I beam, the web of the channel being riveted to the top flange of the I beam; by con-

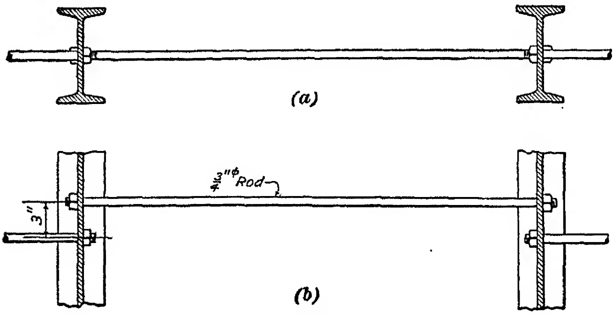


Fig. 44

necting two I beams by means of plates riveted to their top and bottom flanges, as in Fig. 13 (*b*); or by connecting an I beam and a channel in the same manner. Riveted beam girders are employed for heavy construction; for lighter construction, bolted beam girders are used. Bolted beam girders are made up of two or more I beams, of two channels, or of I beams and channels, which are held in place by means of *separators* and bolts.

The separators in common use are of two types: cast-iron separators and gas-pipe separators. A bolted beam girder composed of two I beams connected by means of cast-iron

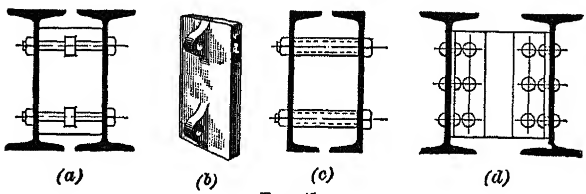


Fig. 45

separators and bolts is shown in Fig. 45 (*a*), the separator being shown in perspective in (*b*); a bolted beam girder composed of two channels connected by means of gas-pipe separators and bolts is shown in (*c*). The cast-iron separators hold the

beams rigidly and make them act as one member, but when concrete is to be poured between the beams they are not so desirable as gas-pipe separators, because they separate the concrete into blocks. For heavier construction the two beams are often connected by means of *diaphragms*, which are either short pieces of **I** beam or channel, or a built-up section composed of plates and angles riveted together as in (*d*); these diaphragms are usually riveted to the webs of the **I** beams or channels.

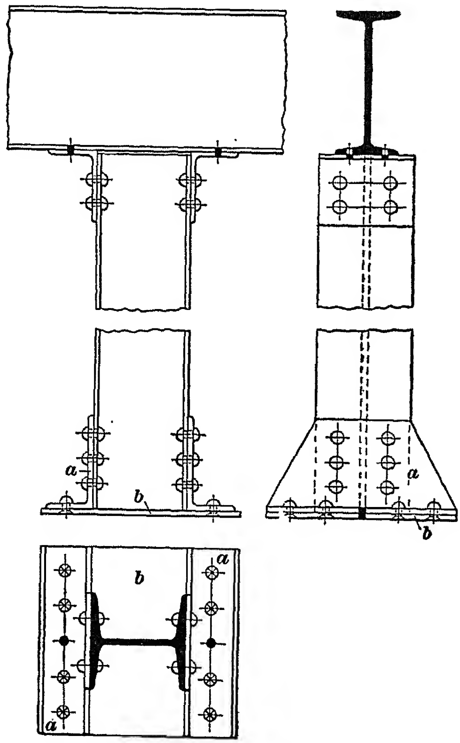


Fig. 46

50. Single-Shape Columns.—Columns are frequently constructed of single shapes, such as **I** beams, angles, channels, and **H** sections. In the construction of New York subways, most wall columns employed are **I** beams. In the usual construction, **I**-beam or channel sections are not suitable for columns because they have little resistance to buckling in a direction perpendicular to their webs. However, in special work where the columns are imbedded in concrete and thus kept from buckling in a plane perpendicular to their webs, as in subway construction, **I**-beam and channel sections may be advantageously employed. Single angle sections are used for columns only in specially light and unimportant construction.

The **H** section, on the other hand, is particularly efficient as a column and is extensively used. A variety of **H** sections are rolled by the Bethlehem Steel Company. The properties and dimensions of those sections are given in the Catalogue of Bethlehem Structural Shapes. In Table VIII are given the dimensions for **H** beams rolled by the Carnegie Steel Company.

In Fig. 46 are shown details of a column of **H** section supporting an **I** beam. In order to distribute the load carried by the column over a sufficient area of the masonry on which it rests, a *base* is constructed at its lower end. The base is a combination of plates and angles riveted to the lower end of the column. That shown in Fig. 46 consists of two $8'' \times 3\frac{1}{2}'' \times \frac{1}{2}''$ base angles *a*, and a $\frac{3}{4}$-inch base plate *b*. The base angles are riveted to the column by three rows of rivets, while the base plate is riveted to the base angles by means of rivets which are countersunk on the under side of the plate in order to provide a smooth bearing surface. Before the column is riveted to the base plate, the column should be milled or finished in order to make its end perfectly smooth and level so that it will bear evenly on the base plate. The line along which the finishing is to be done is generally indicated on the detail drawings of the column by a note *Fin.* or *Mill.* At the upper end of the column is constructed the *cap* which in this case consists of two angles.

ERECTION MARKS AND ERECTION DIAGRAMS

51. Erection Marks.—Before each member leaves the shop an erection mark, or shipping mark, should be conspicuously painted on it. This mark should appear on the detail drawing of the member and also on the *erection diagram* which will be explained later.

The erection marks usually consist of a capital letter and a number. The capital letter should preferably suggest the type of member, as *B* for beam, *C* for column, *G* for girder, and *T* for truss. Thus, the beam detailed in Fig. 28 was marked *B7*, and the beams detailed in Fig. 43 were marked *B12*, *B17*, and *B18*. This system of marking will be used in this Section.

52. Another system of marking, which is used for tall office buildings, not only helps distinguish the members but also facilitates erection. In this system each beam is marked by a designating number and the number of the floor to which the member belongs, as *117-4th FL.*, or *16-ROOF.* Each girder is marked by the letter *G*, a designating number, and the number of the floor to which it belongs, as *G10-7th FL.* Each column is marked by the abbreviation *COL.*, a designating number, and, in parenthesis, the numbers of the floors between which it extends, as *COL. 11 (3-5)*, or *COL. 7 (10-ROOF)*.

53. When the sysem of marking mentioned in Art. **51** is used, all members of the same structure that are of identical

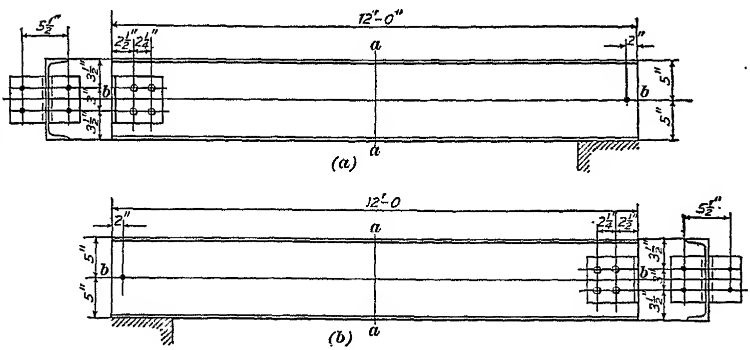


FIG. 47

construction and are completely interchangeable are marked with the same erection mark and are detailed in one drawing. Thus, the beam *B12* detailed in Fig. 43 (*a*) applies to two beams of identical construction. Interchangeable members may not always be framed in the same position in the structure. For example, the two beams drawn in Fig. 47 frame in different positions in the structure, but if the beam shown in (*b*) were first reversed about its center line *a–a* and then about its center line *b–b*, it would be found to agree exactly with the beam shown in (*a*); hence, one drawing would be used for the two beams because they are exactly interchangeable. This case is comparatively simple. More complex cases occur

in practice, and the draftsman must exercise great care in determining whether one member is identical with another member, regardless of the positions in which the two members are framed.

To save time in drawing, two or more members that differ but slightly in their construction, and that have different erection marks, may be detailed in one drawing. Thus, Fig. 43 (*a*) applies to two beams, *B12* and *B17*, which are not of the

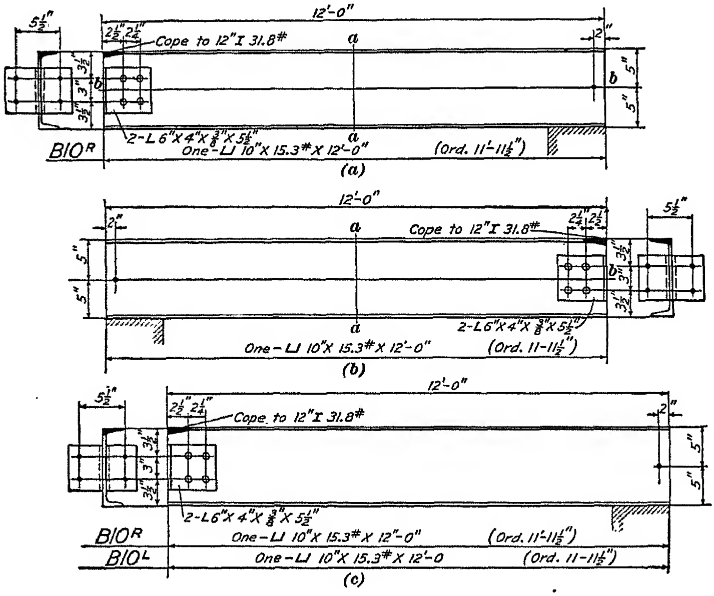


FIG. 48

same construction, because one group of holes is to be punched in *B12* and not in *B17*. The difference in construction between the members to which the drawing applies is specified by some suitable note, as was done in Fig. 43 (*a*) by the note, *In B12 only*.

54. Opposite Members.—In Fig. 48 (*a*) and (*b*) are illustrated two members that are similar in every detail to the two interchangeable members shown in Fig. 47, except that the top flanges in Fig. 48 are coped. Offhand, it would seem that the

two members shown in Fig. 48 (*a*) and (*b*) are also interchangeable, but upon closer investigation it is found that if the member shown in (*b*) were reversed about the center line *a–a* and then about the center line *b–b*, it would agree in every detail with the member shown in (*a*), except that the coped flange would be on the bottom instead of on the top. The two members are of similar construction and have identical structural features, but these features are arranged in exactly opposite positions, so that however the member shown in (*b*) is turned it cannot be made to agree with the member shown in (*a*). If the member shown in (*b*) were turned about axis *a–a* and placed before a mirror, its reflection would be the same as the member shown in (*a*).

Two members that have identical structural features arranged in exactly opposite positions, so that however one of the members is turned it does not agree with the other member, are said to be *opposite members;* they are usually referred to as *rights* and *lefts*. Such members cannot be interchanged in the structure, and great care should be exercised to distinguish them from interchangeable members.

If a member is the exact opposite of another member, it is customary to make one drawing for the two members, with the understanding that the drawing as shown will be used for the construction of one member and that the exact reverse of that drawing will be used for the construction of the other member. The member shown is designated *right* by adding the capital letter R to its erection mark while the other member is designated *left* by adding the capital letter L to its erection mark, as in Fig. 48. The correct way of detailing the two opposite beams shown in Fig. 48 (*a*) and (*b*) is shown in (*c*). No member should be marked right unless there is a member opposite to it in the same structure. The beams $B1^R$ and $B1^L$ in Figs. 10 and 11 are opposite.

55. Erection Diagrams.—In order that the various details of a proposed structure may be drawn in a systematic and uniform manner, the first step usually taken in the detailing office after the design drawings are received is to draw the erection

diagrams. These erection diagrams consist of plans and elevations of the steelwork on which the general dimensions of the structure, the sizes and erection marks of the various members, and other general information are given. Thus, the plan of the second floor of the shop building shown in Fig. 12 (*a*) is an erection diagram. The beams and girders on the erection plans are usually represented by single lines, heavy lines being used for girders and medium lines for beams. The outlines of the bearing plates are drawn in somewhat lighter lines than the beams, and the outlines of the masonry are drawn in light lines that are sufficiently heavy to print distinctly. Sometimes, blue or red ink, or black India ink diluted with water, is used in drawing the outlines of the masonry. To show the manner in which a channel is framed, part of its top flange is drawn, as for the channels marked *B6* and *B8* in Fig. 12 (*a*). The beams that support the masonry and floor loads over windows and other openings in the wall, which are commonly known as *lintels*, are shown on these plans, as lintels *L1* in Fig. 12 (*a*).

The erection diagrams should show not only the general dimensions of the members of the structure but also the typical manner in which they connect to one another. Hence, the erection plans of the various floors should be supplemented with typical sections, details and notes to make the construction clear. Thus, the details shown in Fig. 12 (*b*), (*c*), and (*d*) illustrate clearly the framing of the various members in the plan view in (*a*). The erection diagrams of simple structures, such as the shop building in Fig. 12, may be drawn on a single sheet; for large structures, such as tall office buildings, warehouses, and mill buildings, several sheets may be required to draw the various plans and sections.

56. The erection diagrams serve several purposes. First, they present a summary of the main material used in the structure, and thus facilitate ordering the shapes for the main members from the mill before the detailing of the structure has been completed. Second, they may be sent for approval to the designing department or customer, and thereby make sure

that the various details contemplated are satisfactory. Third, if the design drawings in any way fail to supply all the information necessary for detailing the structure, such deficiencies become apparent when the erection diagrams are drawn, and the needed information is requested from the designers before the detailing has well begun, thereby avoiding delay. Fourth, the erection diagrams are of use to the contractor in constructing all parts of the structure that may be built before the steelwork is erected. Thus, upon receipt of an erection diagram as in Fig. 12, the contractor can build the concrete piers for the support of the columns and set the bolts so that they will fit the steelwork. Fifth, the erection diagrams are usually drawn by the more experienced draftsmen, who establish the principal details that are most suitable for the type of construction dealt with, and therefore facilitate the subsequent detailing, which may be done by less-experienced men. Furthermore, uniformity of construction throughout the structure is assured, regardless of the number of draftsmen that may be employed on the job. The erection diagrams are also of use in checking the drawings. Sixth, the erection diagrams are of help to the shopmen and the shop inspectors in taking care that all necessary provisions for the connection of the various members to one another in the field are made. Finally, and most important of all, the erection diagrams guide the erectors in putting up the steelwork in a systematic manner. Therefore, all identification marks for the various members of the structure should be properly shown, and all notes and details that might aid the erectors in assembling the steelwork should be given. Particular pains should be taken to show everything clearly, so that no misinterpretation, which might cause delay and errors in the field, will be possible.

It is not always possible to complete the erection diagrams before the detailing is begun. In fact, in some classes of work certain information can be given on the erection diagrams only after the details have been completed. In such cases, the erection diagrams are completed as far as possible and sent for approval in the usual manner, and the missing information is added as soon as it can be supplied.

PLATE 2: DETAILS OF BEAMS AND COLUMN

57. Details of Beams for Shop Building.—In Plate 2 are to be drawn the details of the steelwork for the second floor of the shop building shown in Fig. 12. Before the work of drawing the plate is begun, the following explanations should be carefully read.

The elevations of the main beams in the floor are fixed on the erection diagram in Fig. 12 (*c*), where the 8-inch, 9-inch, and 10-inch **I** beams are shown located 4 inches below the top of the finish of the second floor; this location also applies to the 10-inch and 9-inch channels. The 15-inch **I** beams are $2\frac{3}{8}$ inches below the top of the finish; or $1\frac{5}{8}$ inches above the other beams, which is equal to the distance *o* between the top of a 15″ **I** 60.8 lb. and the bottom of the fillet of the top flange, as given in the ninth column in Table IV. In other words, the 15-inch **I** beams are so set that the tops of all beams which frame into them clear their fillets.

Since the 15-inch **I** beams obviously control the connections of the other beams, it is best to begin the drawing by detailing them. An inspection of the plan view in Fig. 12 (*a*) shows that all 15-inch **I** beams used in the floor are of the same construction, because the beams on one side of the column are interchangeable with those on the other; one sketch will therefore suffice. The 15-inch **I** beams are supported by the 6-inch **H** columns in the manner shown in Fig. 12 (*d*), a clearance of $\frac{1}{2}$ inch being allowed between the ends of the beams over the support. In drawing the sketch for the beam, the end supported by the column should be on the left and the one supported by the wall on the right, because, as a rule, in detailing, all extension figures should be given from the more definite of the two ends, and the wall-bearing end is the less definite of the two.

58. All beams that frame into the 15-inch **I** beams are either of 10-inch, 9-inch, or 8-inch depth, and hence the same standard connection angles will be used in all cases. In this type of construction the holes in the web of each 15-inch

I beam provided for the connections of the other beams should preferably line up, as in Fig. 1 of Plate 2. If the lower row of holes in the connection angles for the 8-inch I beams is assumed to be $2\frac{1}{4}$ inches from the bottom flange, the distance between the edge of the connection angles and the bottom flange is $2\frac{1}{4}$ in. $-1\frac{1}{4}$ in. $=1$ inch, which is more than the distance o of $\frac{7}{8}$ inch from the outside of the flanges to the ends of the fillets, given in Table IV. The distance from the upper row of holes to the top flange of the beams is 8 in. $-(2\frac{1}{4}$ in. $+3$ in.$)=2\frac{3}{4}$ inches, which is ample; this location of holes will therefore be adopted. Since the bottom of the 8-inch I beams is 15 in. $+2\frac{3}{8}$ in. $-(4$ in. $+8$ in.$)=5\frac{3}{8}$ inches above the bottom of the 15-inch I beams, the lower row of holes is $5\frac{3}{8}$ in. $+2\frac{1}{4}$ in. $=7\frac{5}{8}$ inches above the bottom of the 15-inch I beams, and the upper row 3 inches above the lower row.

The horizontal location of the various groups of holes in the web of the 15-inch I beams is obtained as follows: Since the clearance between beams over the columns is $\frac{1}{2}$ inch, the distance from the center line of the columns to the edge of the beams is $\frac{1}{4}$ inch. The I beam that frames into the 15-inch I beams over the column support is connected by means of standard connection angles, shown in Fig. 25 in the text, and since the horizontal distance between the holes in those angles is $5\frac{1}{2}$ inches, the distance from the end of each 15-inch I beam to the holes for the connection angle that connects to it is $\frac{1}{2}\times5\frac{1}{2}$ in. $-\frac{1}{4}$ in. $=2\frac{1}{2}$ inches. The center line of the next beam that connects to the 15-inch I beam is distant 4 feet from the center line of the column, or 4 ft. 0 in. $-\frac{1}{4}$ in. $=3$ feet $11\frac{3}{4}$ inches from the end of the I beam; hence, the extension dimension to the center line of the group of holes for that connection is 3 feet $11\frac{3}{4}$ inches. In similar manner are obtained the extension dimensions to the center lines of the other groups of holes in the web. Since at its right end the beam rests on a masonry wall, a hole for a Government anchor should be provided near the center of the beam at a distance of 2 inches from the right end. This hole should not be located by means of an extension dimension, because its location is not dependent upon the location of the other groups of holes.

59. The bearing plates under the 15-inch **I** beams are 16 in.×1 in.×1 ft. 1 in., the 16-inch dimension being along the wall. Hence, each beam projects 13 inches into the wall. Since the distance from the center line of each column to the face of the wall on which the 15-inch **I** beams bear is 16 feet, the figured length of each beam is 16 ft. 0 in.+1 ft. 1 in$-\frac{1}{4}$ in. =17 feet $0\frac{3}{4}$ inches. However, since it is desirable to order beams in lengths that are multiples of $\frac{1}{2}$ inch and when a beam rests on brickwork it does not matter if it projects an additional $\frac{1}{4}$ inch, the ordered and over-all lengths of the beam will be assumed as 17 feet 1 inch.

To locate the holes in the lower flange for the connection of the 15″ **I** 60.8 lb. to the column, the gauge *g* is looked up in Table IV and found to be $3\frac{1}{2}$ inches. As shown in Fig. 12 (*d*) in the text, the 15-inch **I** beams are connected to the 6″×4″ ×$\frac{3}{8}$″ angles in the column cap, the gauge in the 4-inch leg of those angles being $2\frac{1}{2}$ inches. Hence, the distance from the center line of the column to the holes connecting the **I** beam to the column is 3 in.+$2\frac{1}{2}$ in.=$5\frac{1}{2}$ inches, and the distance from the end of the beam to the holes in the flange for that connection is $5\frac{1}{2}$ in.$-\frac{1}{4}$ in.=$5\frac{1}{4}$ inches.

After the details for the 15-inch **I** beams are completed, those for the other beams, shown in Figs. 2 to 8, inclusive, are determined in similar manner. On the drawing, the beams are marked *B1*, *B2*, *B3*, etc., to correspond with Fig. 12 (*a*). In the first and last bays of the floor, the channels at the opposite walls are exactly opposite, and are therefore marked $B6^R$ and $B6^L$.

60. Details of Column.—All columns for the support of the second floor of the shop building are of the same construction, and hence one drawing, Fig. 9 of the Plate, will be used for showing their details. The column is drawn in upright position, a top view, elevation, side view, and bottom-sectional view, being employed to show the details. In the base of the column $1\frac{1}{4}$-inch diameter holes are provided for the $\frac{7}{8}$-inch diameter swedge bolts which connect the columns to the concrete piers under them. The extra large size of hole is

used in order to allow for possible slight inaccuracy in setting the bolts in the concrete. The fact that the holes are of larger diameter than the other holes shown on the drawing should be emphasized by a note and, preferably, a rhombus should be drawn around the figure so that it will not be overlooked. The size of the other holes is covered in the general notes above the title by the statement *Holes* — $\frac{13}{16}''$° *unless noted.*

To provide for uniform bearing of the column on the base plate, the lower end of the **H** is finished. However, it is not necessary to finish the top of the column to provide uniform bearing for the beam on the column, because ample support is provided by the cap angles. In fact, the cap angles should project about $\frac{1}{4}$ inch beyond the top of the **H** section to provide for possible irregularities in the end of the shape due to rapid cutting in the mill. In this case a projection of $\frac{3}{8}$ inch was allowed in order to make the length of the **H** section a multiple of $\frac{1}{2}$ inch.

61. Directions for Drawing Plate 2.—Commence the plate by drawing the border lines, providing space for the title, and dividing the space within the border lines into three parts by means of vertical lines drawn at distances of $6\frac{1}{4}$ inches from the left-hand border line and $4\frac{1}{2}$ inches from the right-hand border line. Now divide the left-hand space into four parts by means of horizontal lines, the top part being $4\frac{3}{4}$ inches deep and each of the other three $2\frac{3}{4}$ inches deep.

Draw the beam *B1* in the space in the upper left-hand corner. First draw line *a b* $1\frac{1}{4}$ inches from the upper border line. Mark along that line point *a* at a distance of $\frac{3}{4}$ inch from the left-hand border line and point *b* at a distance of $\frac{1}{2}$ inch from the right-hand boundary of the part, and through those points draw vertical working lines of indefinite length. From point *a* lay off the 15-inch depth of the beam *B1* to a scale of 1 inch = 1 foot, and draw the outline of the beam as in Fig. 1 on the Plate. With the same scale of 1 inch = 1 foot, lay off the lower line of holes at a distance of $7\frac{5}{8}$ inches from the bottom of the flange, and the upper line of holes 3 inches above.

As previously determined, the actual length of the beam is 17 feet 1 inch, while as drawn, its length is 5 inches to full-size scale; hence, each inch of length shown represents roughly about $3\frac{1}{2}$ feet actual length. With that rough scale in mind, the center lines of the various groups of holes may be located by eye or by scale; thus, 3 feet $11\frac{3}{4}$ inches may be roughly represented by $1\frac{1}{8}$ inches full size, 7 feet $11\frac{3}{4}$ inches by $2\frac{1}{4}$ inches, 11 feet $11\frac{3}{4}$ inches by $3\frac{3}{8}$ inches, and 15 feet $9\frac{5}{8}$ inches by $4\frac{1}{2}$ inches. The holes on each side of these center lines may be located to the scale of 1 inch = 1 foot, which scale may also be used for locating the first line of holes $2\frac{1}{2}$ inches from the left end of the beam and the hole for the Government anchor 2 inches from the right end of the beam. Show all dimensions as in Fig. 1.

Proceed by drawing the bottom-sectional view in order to locate the holes in the bottom flange. Lay off the center line *d e* at a distance of $\frac{3}{4}$ inch full size below the bottom of the beam, and on each side of that center line lay off one-half of the flange width and web thickness to the scale of 1 inch = 1 foot, using the data for a 15″ I 60.8 lb. given in Table IV. Complete the view as in Fig. 1. Web thicknesses and similar small dimensions are generally laid off by eye.

62. In the space below Fig. 1 draw the detail drawing for the beams marked *B2* in Fig. 12 (*a*) in the text. However, bear in mind that in beam detailing the more definite end of the beam should be made the left end, because from that end are measured all extension dimensions. Hence, imagine that the plan is turned around and the beam is seen in such a position that its connection to the 15-inch I beam is on the left end and its support on the masonry wall is on the right end. Draw the top of the beam, line *a b*, at a distance of $\frac{7}{8}$ inch from the upper boundary line of the space. Lay off point *a* $1\frac{1}{2}$ inches from the left-hand border line and through that point draw a light line marking the left end of the beam. The right end of the beam will be in the prolongation of line *b e* of the beam *B1*. Using a scale of 1 inch = 1 foot, lay off the 9-inch depth of the beam and complete its outline.

The length of the beam may be found as follows: Since in this case one end of the beam is supported on a masonry wall, no clearance need be allowed between the backs of the connection angles of the beam and the web of the 15″ I 60.8 lb. into which it frames; hence, the distance from the center of the 15″ I 60.8 lb. to the backs of the connection angles is not the distance h in Table IV but one-half of the web thickness of the 15-inch I beam, or $\frac{5}{16}$ inch. At the right end, the beam is supported by an $8'' \times \frac{5}{8}'' \times 1'\ 0''$ bearing plate so that the length of bearing is 8 inches. Hence, the theoretic length of the beam is 16 ft. 0 in. $-\frac{5}{16}$ in. $+8$ in. $=16$ feet $7\frac{11}{16}$ inches; a nominal length of 16 feet $7\frac{3}{4}$ inches will be used, it being impractical to express lengths in sixteenths of an inch when one end is bearing on a masonry wall. The ordered length would be 16 feet $7\frac{1}{2}$ inches.

The beam *B2* connects to the beam *B1* by means of standard connection angles, details of which are given in Fig. 25 in the text. According to Fig. 12 (*c*) in the text, the bottom of beam *B2* is above the bottom of beam *B1* a distance of 15 in. $+2\frac{3}{8}$ in. $-(9$ in. $+4$ in.$)=4\frac{3}{8}$ inches. Since the lower line of holes in beam *B1* is located $7\frac{5}{8}$ inches from the bottom of the beam, the location of the lower line of holes in beam *B2* is $7\frac{5}{8}$ in. $-4\frac{3}{8}$ in. $=3\frac{1}{4}$ inches from the bottom of the beam. The left end of the beam may now be detailed as in Fig. **2**. To draw the end view, locate the center line *d e* at a distance of $\frac{3}{4}$ inch from the left-hand border line, and draw the beam according to the dimensions given in Table IV, showing the fillets with free-hand curves. Complete the drawing of beam *B2* as in Fig. **2**.

The beams *B2* are used only in the end bays of the floor, three such beams being required in each end bay; hence, the total number of beams *B2* required for the floor is $2 \times 3 = 6$.

63. The beam *B3* may now be detailed by methods similar to those described for beams *B1* and *B2*. Since beam *B3* frames between two 15″ I's 60.8 lb., the distance from the center line of the 15″ I 60.8 lb. to the backs of the connection angles of beam *B3* is the distance h in Table IV, or $\frac{3}{8}$ inch. The 15-inch I beams are 16 feet center to center and the nominal

length of beam *B3* is therefore 16 ft. 0 in. $-2\times\frac{3}{8}$ in. $=$ 15 feet $11\frac{1}{4}$ inches. The ordered length of the I beam is $\frac{3}{4}$ inch less, or 15 feet $10\frac{1}{2}$ inches. The beam may now be detailed without much difficulty. As is evident from Fig. 12 (*a*) in the text, seven such beams are used in each bay of the building except the end bays, and since there are five intermediate bays in the building, $7\times5=35$ beams are required for the floor.

The beam *B4* is connected to a 10″ ⊔ 15.3 lb. at the left end and to a 15″ I 60.8 lb. at the right end. Since both ends are equally definite, it is not necessary to turn the drawing as was done in detailing beam *B2*. According to Table III, the distance *h* from the back of the 10″ ⊔ 15.3 lb. to the back of the connection angles for beam *B4* is $\frac{5}{16}$ inch, and as found for beam *B3* the distance from the center line of the 15″ I 60.8 lb. to the back of the connection angles framing to its web is $\frac{3}{8}$ inch. Since the distance from the back of the 10″ ⊔ 15.3 lb. to the center line of the 15″ I 60.8 lb. is 12 feet 0 inches, the nominal length of beam *B4* is 12 ft. 0 in $-(\frac{5}{16}$ in. $+\frac{3}{8}$ in.) $=$ 11 feet $11\frac{5}{16}$ inches. The ordered length of beam, however, is about $\frac{3}{4}$ inch less, or 11 feet $10\frac{1}{2}$ inches. The top of beam *B4* is flush with the top of the 10″ ⊔ 15.3 lb. into which it frames, and hence its top flange is coped to clear the top flange of the channel. The connections will be made by means of standard connection angles. As determined in Art. 58, the bottom row of holes for the connection angles will be located $2\frac{1}{4}$ inches from the bottom of the beam. The beam may now be detailed as in Fig. 4. Since according to Fig. 12 (*a*) in the text, two such beams are required in each end bay, the number of beams *B4* in the floor is four.

64. Next, divide the middle part of the plate into five spaces, the depth of the top space being $3\frac{1}{4}$ inches, and of each of the three following spaces $2\frac{3}{4}$ inches, so that the depth remaining for the bottom space is $1\frac{1}{2}$ inches. Draw two vertical working lines the entire depth of the plate for the ends of the beams, one line $\frac{1}{2}$ inch to the left of the right-hand boundary line of the part, and the other $1\frac{1}{2}$ inches to the right of the left-hand boundary line of the part. In the top space, detail beam

B5 in the manner shown in Fig. **5**. Since the beam frames at its right end into beam *B1* and at its left end rests on the wall, in detailing the beam the plan will be turned around so that the more definite end will be shown at the left. The standard bearing plate required for a 10″ **I** 25.4 lb. is $8'' \times \frac{3}{4}'' \times 1'\ 0''$, and the length of bearing is 8 inches. For reasons previously explained, the distance between the center line of the 15″ **I** 60.8 lb. and the back of the connection angles of beam *B5* is one-half the web of the 15-inch **I**, or $\frac{5}{16}$ inch. The length of the beam is the same as the length of beam *B2*, or 16 feet $7\frac{3}{4}$ inches. The bottom of beam *B5* is 1 inch below the bottom of beam *B2*, and hence the bottom row of holes in the web and in the connection angles is $3\frac{1}{4}$ in. $+1$ in. $= 4\frac{1}{4}$ inches from the bottom of the beam. The distance from the left end of the beam to the center line of the group of holes for the connection of beam *B8* to the web of beam *B5* is 12 ft. 0 in. $-\frac{5}{16}$ in. $-\frac{1}{8}$ in. $= 11$ feet $11\frac{9}{16}$ inches. Since two beams *B5* are required in each end bay, the total number of such beams required is four.

The details of the beam shown in Fig. **6**, for the opposite members $B6^R$ and $B6^L$, are practically identical with the details of beam *B2*, except that in the end view the section shown is a channel. Also, the details of the beam *B7*, in Fig. **7**, are determined in the same manner as the details of the beam *B3*.

The beam *B8*, in Fig. **8**, frames between two 10″ **I**'s 25.4 lb., *B5*, with which it is flush, top and bottom. According to Table IV, the distance *h* for a 10″ **I** 25.4 lb. is $\frac{1}{4}$ inch, and since the distance between the center lines of the two beams *B5* is 12 feet 0 inches, the nominal length of *B8* is 12 ft. 0 in. $-2 \times \frac{1}{4}$ in. $= 11$ feet $11\frac{1}{2}$ inches. Both the top and bottom flanges of *B8* will be coped at each end of the channel. The distance from the bottom of the channel to the bottom row of holes in the connection angles and the web is $4\frac{1}{4}$ inches, the same as for beam *B5*. The extension dimensions to the groups of holes for the connections of beams *B4* are respectively 4 ft. 0 in. $-\frac{1}{4}$ in. $= 3$ feet $11\frac{3}{4}$ inches, and 8 ft. 0 in. $-\frac{1}{4}$ in. $= 7$ feet $11\frac{3}{4}$ inches, from the left end of the beam. One such beam is required in each half of the floor, or two beams in the entire floor.

In the bottom space on the Plate are specified the number of Government anchors and the number of various bearing plates required for the support of the wall-bearing **I** beams and channels. Note that the bearing plates specified for the 15-inch **I** beams are 1 foot 1 inch long instead of 1 foot 4 inches, the standard length given in Table IV. The shorter length was adopted in this case because the thickness of the brick pilasters that support the 15-inch **I** beams is 17 inches, and at least 4 inches of masonry should be allowed from the edges of the bearing plates to the outside of the pilasters to protect the plates from the weather.

65. Next, divide the right-hand part of the Plate into one space $9\frac{1}{4}$ inches deep for the details of the **H** column, and one space $1\frac{1}{2}$ inches deep for the general notes of the drawing, the remainder being reserved for the title of the Plate.

In detailing the column commence by drawing line *a* in the elevation $1\frac{1}{2}$ inches, full size, from the right-hand border line, the backs of the cap angles $2\frac{1}{8}$ inches from the upper border line, and the backs of the base angles $6\frac{3}{8}$ inches from the upper border line. Complete the elevation by laying off all dimensions except the length to a scale of 1 inch = 1 foot. Next, draw the side view, drawing line *b* at a distance of $3\frac{1}{8}$ inches, full size, from the right-hand border line, and laying off all details to the scale of 1 inch = 1 foot. After completing the side view, draw the top view of the column, locating the center line *c* $1\frac{1}{4}$ inches, full size, from the upper border line, and drawing the view to the scale of 1 inch = 1 foot. Finally, draw the bottom-sectional view, locating the center line *d* $1\frac{5}{8}$ inches from the bottom boundary line of the space. Complete the details and notes as in Fig. 9.

In the space below the column, draw the guide lines for the general notes, and letter the notes given in that space. Since all rivets shown on the drawing are $\frac{3}{4}$-inch diameter, their size is covered by the note *Rivets*—$\frac{3}{4}''^{\circ}$. However, the open holes are not all $\frac{13}{16}$ inch in diameter, because two $1\frac{1}{4}$-inch diameter holes are used in the base of the column *C1*; hence, the size of all holes shown is covered by the note *Holes*—$\frac{13}{16}''^{\circ}$ *unless*

noted. Although the paint is specified in this drawing, it is the general practice in the larger drafting rooms not to make such specification on drawings, unless a paint other than what is generally used in the shop has been specified by the customer.

Finally, letter the title as shown in the sample drawing and thus complete the plate.

DETAILS OF PLATE GIRDERS AND RIVETED COLUMNS

PLATE GIRDERS

66. Use of Plate Girders.—Of the various types of riveted girders, the plate girder is most widely used. In heavy office-building construction, it is employed to support the floorbeams when the strongest I beam available is too weak for that purpose; it is sometimes also used to support thick walls over large openings. In mill-building and factory construction, it is well adapted for the support of traveling cranes and heavy machinery. In bridge construction, it is used very extensively for the support of the floor, and for the principal members of the structure.

67. Principal Parts of Plate Girders.—In Fig. 49 is shown a perspective view of a part of a plate girder. The angles *a* are the *flange angles*, the upper pair forming the *top flange angles*, and the lower pair the *bottom flange angles*, of the girder. The two flanges are connected by means of the *web plate b*, to which are riveted the flange angles. To stiffen the plate against buckling, the *stiffener angles*, or *stiffeners c*, are riveted to the web and flange angles. Additional area in the flanges may be obtained by means of one or more *flange*, or *cover*, *plates d*, which are riveted to the top and bottom flange angles. Since the stresses in the flanges of the girder are greatest at the center, and from there decrease to the ends, it is not necessary to run the cover plates the full length of the girder. In fact, the general practice is to stop the cover plates at points beyond which they are no longer necessary. However, when girders are to be

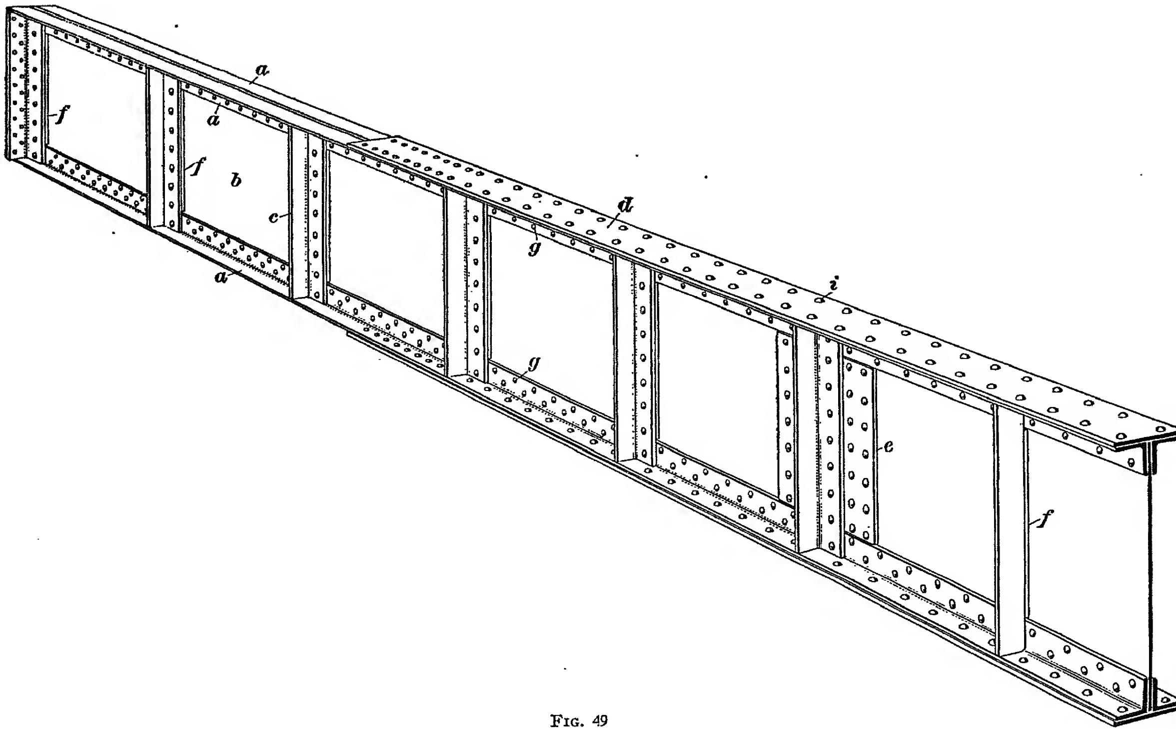


FIG. 49

exposed to the weather, it is best to run one top cover plate the full length of the girder in order to protect the surfaces in contact between the angles and the web. It frequently happens in girder construction that it is impossible to obtain a web plate long enough to run the full length of the girder. The web plate is then spliced by means of *splice plates e*, which are riveted to the web.

68. Connections of Girder to Column.—The usual method of connecting a girder to a column is by riveting the outstanding legs of the end stiffeners to the web or the sides of the column, as in Fig. 50. Seat angles *a* are frequently riveted to the column to provide a support for the girder during erection. The girders are usually bolted to the seat angles. Sometimes, it is found most advantageous to connect a girder to a column by means of a bracket and top angle, as shown in Fig. 34 for an I beam.

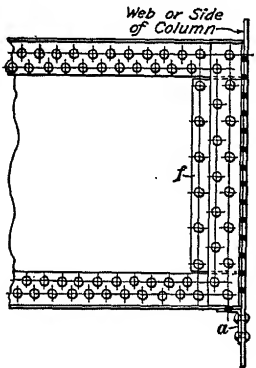


Fig. 50

When a girder rests on top of a column the connection may be made in the manner shown in Fig. 51. A $\frac{3}{4}$-inch cap plate *c* is usually riveted to the top of the column, and the girder is riveted to the cap plate. Two pairs of stiffener angles should be employed in the girder over the column, the outstanding legs of the stiffener angles being in line with the outstanding legs of the angles of the column.

69. Girder Supported by Masonry Pier.—A typical detail of the end of a girder supported by a masonry pier is shown in Fig. 52. The load from the girder is distributed over a sufficient area of masonry by means of two plates, of equal size and thickness, specially proportioned for that purpose. The upper plate *a*, called the *sole plate*, is riveted to the bottom flange of the girder by means of rivets which are countersunk on the bottom, while the lower plate *b*, known as the *masonry plate*, is usually shipped loose. Both plates are anchored to

the masonry by means of anchor bolts *c*, one on each side of the girder.

70. Methods of Detailing Girders.—In detailing girders it is customary to represent them on the drawing to some scale, such as $\frac{3}{4}$ inch = 1 foot or 1 inch = 1 foot. If a girder is symmetrical about its center line, or nearly symmetrical, only one-half of the girder, usually the left half, need be shown, and the fact that the part not shown is similar is indicated by a suitable note. In Fig. 53 are shown typical details of a girder

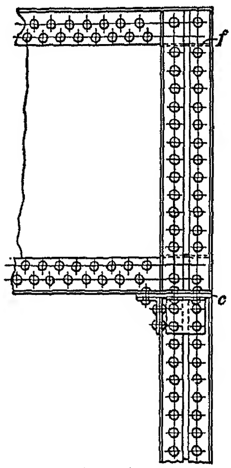


Fig. 51

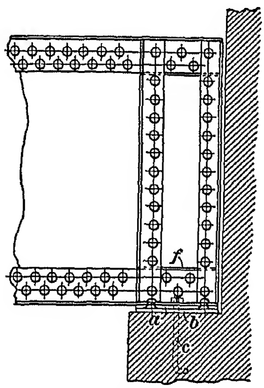


Fig. 52

designed for the support of an overhead traveling crane in a mill building. The top flange of the girder is not symmetrical about the center line; nevertheless, only one half of the girder is drawn, and the construction of the top flange, which is not symmetrical, is indicated by suitable notes and a sketch. The views generally shown are the top view, front elevation, bottom-sectional view, and end view, and one or more cross-sections.

The main dimensions of the plate girder that should be determined before the various details are drawn are the extreme length and the distance back to back of the flange angles. The *nominal depth* of the girder is the depth of its web, which

for the shallower girders is in even inches and for the deeper girders in even half feet. In the usual construction, the flange angles are riveted to the web so that their backs project $\frac{1}{4}$ inch beyond the ends of the web, in order to allow for possible irregularities in the sheared edges of the plate. The distance back to back of flange angles is therefore $\frac{1}{2}$ inch greater than the nominal depth of the girder. In some construction the backs of the flange angles project only $\frac{1}{8}$ inch beyond the edges of the plate, and the distance back to back of flange angles is then $\frac{1}{4}$ inch greater than the nominal depth of the girder. When the upper edge of the web is exposed to weather conditions, as is sometimes the case in plate girders for bridges and viaducts, the upper edge of the web plate is made flush with the backs of the flange angles to avoid the formation of a rain pocket, while the lower flange angles project $\frac{1}{4}$ inch beyond the lower edge of the plate. In the girder shown in Fig. 53, the web is 48 inches deep and the distance back to back of flange angles is 4 feet $0\frac{1}{2}$ inch, as specified by the dimension *4′–0½″ b. b.* It is the depth back to back of flange angles, not the nominal depth, that is specified on drawings. When stiffeners are employed to reinforce the web plate, the spaces between the stiffeners are known as the *panels* of the girder.

The length of girder specified on drawings is the extreme distance between its ends; when end stiffeners are used, it is the distance back to back of the end stiffeners. The flange angles generally extend the full length of the girder, but the web plate is often made $\frac{1}{4}$ inch shorter at each end. Thus, in Fig. 53 the length of the girder is 41 feet $0\frac{1}{2}$ inch, the length of the flange angles is also 41 feet $0\frac{1}{2}$ inch, but the length of the web plate is 41 feet 0 inches. When no end stiffeners are used, or when the web plate is milled at the ends, the plate extends the full length of the girder.

After the main dimensions of the girder have been established, the distances between the gauge lines in the legs of the stiffeners, or *panel lengths*, should be determined and dimensioned. In Fig. 53 the panel lengths are given in the line below the dimension 41 feet $0\frac{1}{2}$ inch, the extreme length of the

girder. The draftsman may now proceed to draw in the different details and to put in the various dimensions.

71. Stiffeners.—The *end stiffeners*, at the ends of girders besides stiffening the ends of the web, often also serve as connection angles. Since the stiffener angles are riveted on the outside of the vertical legs of the flange angles, spaces are left between the backs of the stiffener angles and the web. It is very undesirable to drive rivets through open spaces because the angles adjoining those spaces are likely to be bent out of line and the rivets are liable to upset in the open spaces; hence, it is customary to pack the openings with plates, known as *fillers*, as *f* in Fig. 49. For end stiffeners, the filler should extend the full width of the leg of the stiffener angle under which it is placed, and preferably should project beyond the leg of the angle, so as to provide another line of rivets, as *f* in Fig. 50. Often the filler is made to extend under two or more angles, as *f* in Figs. 51 and 52.

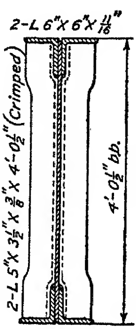


FIG. 54

In addition to the end stiffeners, the webs of most girders are also reinforced with *intermediate stiffeners*, as in Figs. 49 and 53. The spacing of those stiffeners is generally determined by the designer. Beams are often connected to the outstanding legs of intermediate stiffeners, as in Fig. 37, in which case the spacing of the stiffeners is determined by the spacing of the beams; one or more stiffeners are sometimes placed between beams. As shown in Figs. 49 and 53, it is customary to place intermediate stiffeners so that their backs face the nearer end of the girder. The filler under an intermediate stiffener should have the same width as the leg of the angle riveted to it. Instead of using fillers, the intermediate stiffeners are frequently bent, or *crimped*, as in Fig. 54, so that they are in contact with the web of the girder. Such crimping, however, may be employed only in stiffeners that serve mainly to reinforce the web; stiffeners to which other members are connected should not be crimped, because their strength is materially affected by crimping.

72. End and intermediate stiffeners are placed so that they bear against the outstanding legs of the flange angles, and it is therefore necessary to grind the corners of the stiffeners to fit the fillets of the flange angles. The length of straight stiffener angles specified on drawings is the distance between the inside faces of the outstanding legs of the flange angles. In Fig. 53 the distance back to back of flange angles is 4 feet $0\frac{1}{2}$ inch, and the thickness of the legs of the flange angles is $\frac{11}{16}$ inch; hence, the distance between the inside faces of the outstanding legs is 4 ft. $0\frac{1}{2}$ in. $-2\times\frac{11}{16}$ in. $=3$ feet $11\frac{1}{8}$ inches, which is the specified length of the stiffener angles. In computing the length of crimped stiffeners, an allowance for each crimp, equal to the thickness of the flange angles, should be added to the clear distance between flange angles. Thus, in Fig. 54 the distance back to back of flange angles is 4 feet $0\frac{1}{2}$ inch and the length of crimped stiffeners specified is also 4 feet $0\frac{1}{2}$ inch.

The thickness of fillers under stiffeners should be the same as the thickness of the flange angles. In Fig. 53 the thickness of the fillers is $\frac{11}{16}$ inch. The length of filler specified on the drawing should be $\frac{1}{2}$ inch less than the clear distance between the vertical legs of the flange angles, $\frac{1}{4}$ inch clearance being allowed at each end for possible overrun of angles. In Fig. 53 the specified length of filler is 4 ft. $0\frac{1}{2}$ in. $-(2\times 6$ in. $+\frac{1}{2}$ in.) $=3$ feet 0 inches.

73. Spacing of Rivets in Girders.—The rivets that fasten the flange angles to the web, commonly known as *flange rivets*, as *g* in Fig. 49, transfer the stresses in the flanges to the web. They are spaced closer near the ends than near the middle cf the span, because the stresses in the flanges, that tend to shear the rivets, decrease from a maximum at the ends to a minimum near the middle of the span. In determining the spacing of flange rivets, it is customary to compute the maximum pitch that is allowable in each panel, or section of the girder between stiffeners, to resist the maximum shearing stress in the panel, and to use that spacing throughout the panel. In some companies, the maximum pitch of flange

rivets is often specified as in Fig. 53, which is part of a standard drawing of the American Bridge Company, the actual spacing of the rivets being left to the templet makers. In other companies the complete spacing is determined by the draftsman and specified on the drawing, as will be shown later. In spacing the rivets the general rules for rivet spacing given in Arts. **30** to **33** should be taken into consideration. The rivets adjacent to stiffeners should be spaced far enough away from the legs of the angle to permit proper driving, as specified in Art. **33**, even if the rivet spacing at those points exceeds the allowable maximum pitch. Thus, in Fig. 53, while the maximum pitch in the end panel is 2 inches, the spacing at the stiffeners is $3\frac{1}{4}$ inches. In 6-inch or 5-inch legs of angles two gauge lines are generallv used and the rivets are staggered as in Fig. 53.

74. The rivets that connect the cover plates to the flange angles, as *i* in Fig. 49, must safely resist the shearing stresses in them. Generally, it will be found sufficient to employ two single lines of rivets spaced four diameters apart for a distance of about one and one-half times the width of the cover plate near the ends, and not more than the maximum spacing specified in Art. **30** beyond that distance. Thus, the lower cover plate in Fig. 53 is riveted to the flange angles by means of two lines of rivets, in which the rivets are spaced 3 inches apart in a distance of 2 feet from the end rivets and 6 inches apart beyond that distance. Care should be taken to place the rivets that are near the outstanding legs of the stiffeners so that they can be driven without much difficulty. For that reason, it is always best to place one line of rivets in the cover plates in line with the rivets in the stiffeners, as in Fig. 53, or to tie the line of rivets that is nearest to the stiffeners with the line of rivets in the stiffeners. Wherever possible the rivets in the flanges and cover plates should be so arranged that the same templets can be used for the top and bottom flanges.

Standard gauges need not necessarily be used in the flange and stiffener angles. The distance between gauge lines in the vertical legs of the flange angles, or between the rivet lines

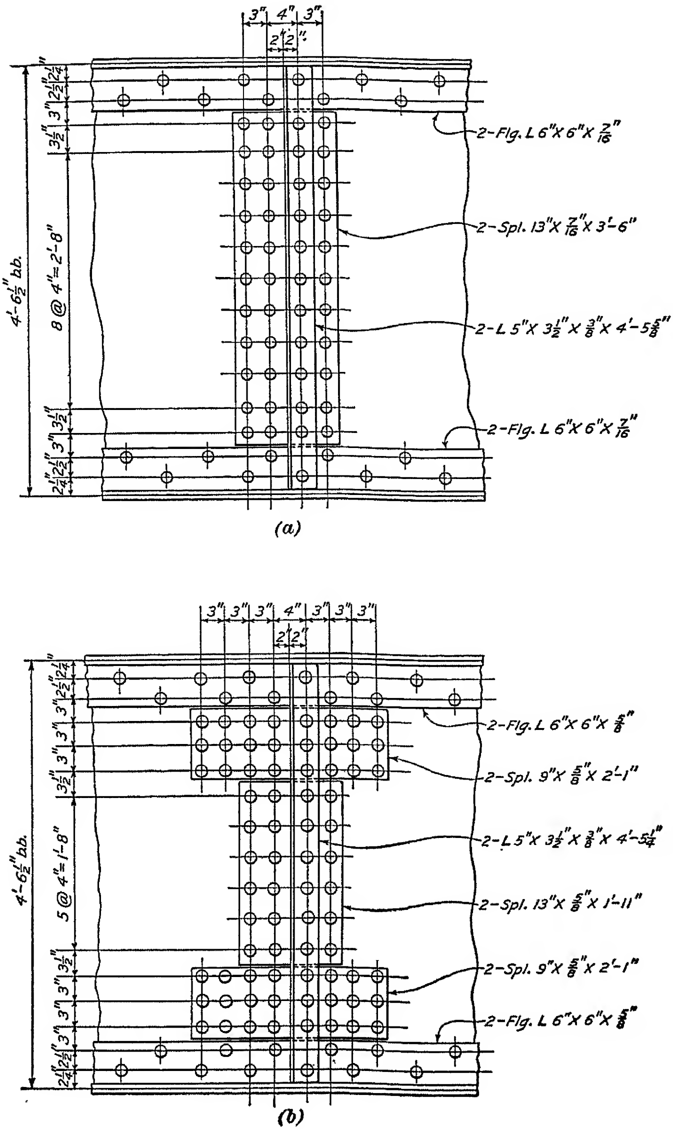

2-Flg. L 6"X 6"X 7/16"
2-Spl. 13"X 7/16"X 3'-6"
2-L 5"X 3 1/2"X 3/8"X 4'-5 5/8"
2-Flg. L 6"X 6"X 7/16"
4'-6 1/2" b.b.
8 @ 4" = 2'-8"
(a)
2-Flg. L 6"X 6"X 5/8"
2-Spl. 9"X 5/8"X 2'-1"
2-L 5"X 3 1/2"X 3/8"X 4'-5 1/4"
2-Spl. 13"X 5/8"X 1'-11"
2-Spl. 9"X 5/8"X 2'-1"
2-Flg. L 6"X 6"X 5/8"
4'-6 1/2" b.b.
5 @ 4" = 1'-8"
(b)

Fig. 55

in the cover plates, is usually expressed in multiples of $\frac{1}{2}$ inch. The gauge lines in the outstanding legs of stiffeners are generally arranged so as to make the connections of the other members of the structure to them most convenient.

75. Girder Splices.—Plates are rolled in certain maximum lengths; usually, the deeper plates are rolled in shorter lengths than the shallower plates. When the length of the girder exceeds the maximum length of web plate obtainable, it is necessary to splice the web plate. In the lighter girders such splices are generally located in the middle of the span, while in the heavier girders two or more splices may be found necessary. The splices should always be amply strong and contain a sufficient number of rivets to transmit the stress in the member spliced. The two types of web splices in common use are illustrated in Fig. 55: the one shown in (*a*) is made by means of two plates, one on each side of the web; the other, shown in (*b*), is made by means of six plates, three on each side of the web. Stiffener angles are generally riveted on the outside of the splice plates; when the thickness of the flange angles exceeds the thickness of the splice plates it is necessary to use fillers under the stiffeners. Fillers less than $\frac{3}{16}$ inch thick should be avoided; therefore, when the difference in thickness between the flange angles and the required splice plates is less than $\frac{3}{16}$ inch, the thickness of the splice plates should be made the same as the thickness of the flange angles. The thickness of each splice plate should be not less than $\frac{5}{16}$ inch for girders used in building construction and $\frac{3}{8}$ inch for girders used in bridge construction.

76. Splices in the flanges of girders are undesirable because however well they are constructed, they tend to weaken the girder; besides, they generally prove costly. In the usual construction they can almost always be avoided, because there is no difficulty in obtaining angles or cover plates of the desired length. For instance, $6'' \times 6''$ angles can be obtained in lengths up to 100 feet, and the usual sizes of cover plates in lengths up to 85 feet. By special arrangement with the mills even longer cover plates and flange angles may be obtained. However,

girders are sometimes constructed from shapes in stock, and when the required lengths of the members of the girder exceed the available stock sizes, splicing is found necessary. Such splices, illustrated in Fig. 56 (*a*), (*b*), and (*c*), are generally made

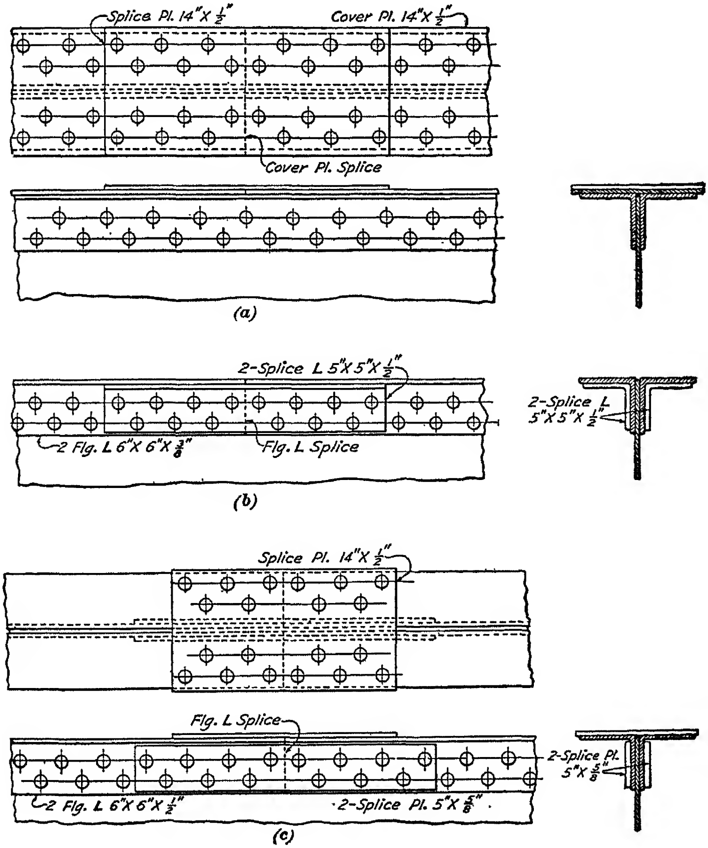


FIG. 56

in the shop. Often, splicing of the web and flanges of girders is made necessary by transportation facilities. Thus, when girders are shipped by boat, it is often found best to ship them in parts and to splice those parts in the field during erection. A typical illustration of a field splice is shown in Fig. 57. In

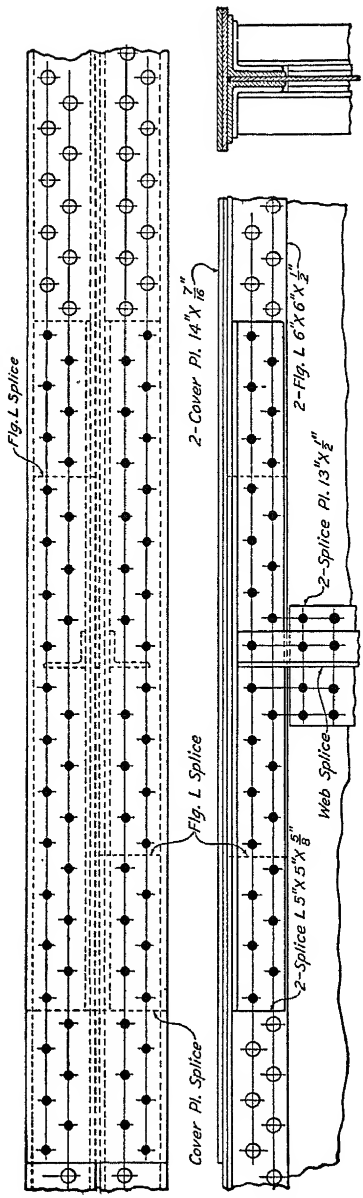


Fig. 57

splicing flanges it is best not to splice two parts of the flange in the same place. In fact, some specifications state that no two parts of the flange should be spliced within 2 feet of each other. This rule, however, leads to the use of long splices; it is regarded by many engineers as too conservative and is not generally observed.

77. Cover plates should be spliced with plates of equal cross-sectional area, as shown in Fig. 56 (*a*). When the girder has two or more cover plates, it is best to splice a cover plate at the point where another cover plate would ordinarily end, and to continue that cover plate beyond the point of splice to make it serve as a splice plate. Flange angles are spliced most efficiently by means of angles of equal cross-sectional area which are riveted to both legs of the flange angles, as shown in (*b*). The vertex of each splice angle is ground to fit the fillet of the flange angle to which it is riveted. The flange angles may also be

spliced by means of plates riveted to the horizontal and vertical legs of the flange angles, as shown in (*c*). In the field splice shown in Fig. 57, the web is spliced as in Fig. 55 (*a*); the lower cover plate is spliced at the point where the upper cover plate would otherwise stop, by prolonging the upper cover plate; one flange angle is spliced at a point about 18 inches to the left of the web splice, and the other at an equal distance to the right of the web splice, by means of angles.

78. Assembling Marks.—Girders, columns, and trusses are often constructed of several pieces, some of which are exactly alike. These identical pieces may be laid out by means of a single templet. For example, in the girder shown in Fig. 53, one templet may be used for all the intermediate stiffeners shown. Identical pieces are also often used in members of the same structure detailed on other sheets. To assist the templet makers in making a single templet for a part that occurs several times on a drawing or on several sheets for the same structure, all pieces, except the main parts, of members are marked on the drawing with *assembling marks*. These assembling marks are later painted on the templets and thus serve as an aid to the men in the shop in selecting the proper templets for the various pieces. After the holes and cuts have been marked on each piece, the assembling mark is painted on it to help the assemblers in assembling, or fitting together, the different parts of the member. In the girder shown in Fig. 53 the stiffeners and fillers are marked with assembling marks, but the main parts—the flange angles, web plate and cover plates—have no such marks. The assembling mark is written after the size of the first piece shown on the drawing, as *s c* after the size of the first intermediate stiffener shown, and all other pieces of the same construction need be marked only with the assembling mark. Thus, the use of assembling marks often saves repeating dimensions and sizes for identical parts.

79. There are several systems of assembling marks in use. The system to be used in this Section is the one employed by the larger structural companies, such as the American Bridge

Company. In this system, the assembling mark consists of two lower-case letters and a number. The first letter is used to indicate the type of the piece, the second letter is used to differentiate from one another pieces that are of the same type but somewhat different in detail, and the number refers to the sheet where the piece first appears. The assembling marks painted on templets or steelwork should consist of the two letters and the number, but in making the drawing it is not necessary to write the number in the assembling marks of pieces that are detailed on the sheet for the first time, it being understood in the shop that wherever such numbers are omitted on the drawing the number of the sheet on which it appears is implied. Thus, in marking the various pieces shown first in Fig. 53 the templet maker would add the number of that sheet. The assembling marks of all pieces which were first detailed on another sheet should include the number of the sheet on which they were first detailed.

The first lower-case letter should preferably suggest the type of piece. All base or cap angles for columns, and all miscellaneous angles that have no special designation, are marked with the letter *a*; the bottom seat angles for beam connections are designated *b*; column base plates, cap plates, or splice plates, are designated *c*; all fillers that have more than one line of rivets are marked *d*, while all fillers that have only one line of rivets are marked *f*; all bent plates or angles are marked *h*; miscellaneous plates which have no other designation are marked *p*; stiffener angles that are fitted at one end only are marked *k*, while those that are fitted at both ends are marked *s*; the top angles for beam connections are marked *t*; light web members for trusses are marked *w*, and lattice bars are marked *y*.

The second letter is chosen in alphabetical sequence, the letters *e*, *i*, *l*, *o*, *q*, and *u* being usually omitted because they can be readily confused with other letters. Thus, the first pair of stiffeners on a drawing is generally marked *s a*, the second pair of somewhat different detail is marked *s b*, the third pair is marked *s c*, the fourth pair *s d*, and the fifth pair *s f*, etc.

AMERICAN BRIDGE COMPANY

LINE	NO. PCS.	SHAPE				LENGTH FT.	LENGTH INS.	ASSEMBLING MARK	REMARKS	CALCULATED WEIGHT FOR ONE MEMBER	ORDERED NO.		ORDERED FT.	ORDERED INS.	ITEM
1															
2		ONE GIR. G41 (2nd FL.)													
3															
4	2	L	6	6	1/2	20	0								33
5	2	L	6	6	1/2	20	6								32
6	1	Web		39	1/2	19	11								29
7	2	Cov.		14	1/2	20	7								36
8	2	Cov.		14	7/16	9	6								37
9	2	Pl.		12	1/2	3	1 1/2	1-ha R 1-ha L							s
10	2	Pl.		11	1/2	3	1 1/2	1-hb R 1-hb L							s
11	4	Pl.		27	1/2	3	9	pa							49
12	4	L	5	3 1/2	3/8	3	2 1/2	2-sa R 2-sa L	FIN.						s
13	2	L	6	3 1/2	3/8	3	2 1/2	1-sb R 1-sb L	FIN.						s
14	4	L	5	3 1/2	3/8	3	1 1/2	2-sc R 2-sc L							s
15	4	Fil.		3 1/2	1/2	2	3	fa							s
16	1	Fil.		8	1/2	1	3	da							s
17															
18															
19		ONE GIR. G42 (2nd Fl.)													
20															
21	2	L	6	6	1/2	20	0								33
22	2	L	6	6	1/2	20	6								32
23	1	Web		39	1/2	19	11								29
24	2	Cov.		14	1/2	20	7								36
25	2	Cov.		14	7/16	9	6						19	0	37
26	2	Pl.		12	1/2	3	1 1/2	1-ha R 1-ha L							s
27	2	Pl.		11	1/2	3	1 1/2	1-hb R 1-hb L				12	30	1	s
28	4	Pl.		27	1/2	3	9	pa							49
29	4	L	5	3 1/2	3/8	3	2 1/2	2-sa R 2-sa L	FIN.						s
30	2	L	6	3 1/2	3/8	3	2 1/2	1-sb R 1-sb L	FIN.						s
31	4	L	5	3 1/2	3/8	3	1 1/2	2-sc R 2-sc L							s
32	4	Fil.		3 1/2	1/2	2	3	fa							s
33															
34															
35															
36															
37															
38															
39															
40															

RIVETS	HOLES	NAME / DATE	DATE	DRAWINGS / FABRICATION	ORDER NO.	SHEET NO.
3/4"	13/16"			DRAWINGS ✓ FABRICATION ✓	✓	G7

NAME OF STRUCTURE

FIG. 58

80. All pieces that are of exactly the same detail and are interchangeable are marked with the same assembling mark. The first time the piece appears, it should be completely detailed, and thereafter it need only be marked with the assembling mark. If two pieces are exactly opposite, and not interchangeable, one piece should be marked *right* by adding the capital letter R to its assembling mark, and the opposite piece should be marked *left* by adding the letter L to its assembling mark. When only one of the two opposite pieces is shown in a view of the drawing, the piece shown is assumed to be the right and the other piece the left. In Fig. 53, the stiffeners $s\,b$ and $s\,c$ shown in the elevation could be interchanged with those on the opposite side of the girder by simply turning them end for end. The end stiffener, on the other hand, could not be interchanged with that on the opposite side of the girder, because if it were turned end for end the open holes required for the connection of other members to the girder would not be in the right position, and hence the stiffeners on the two sides of the girder are opposite. The end stiffener shown in the elevation is right and is marked $s\,a^R$, while that on the opposite side of the girder is left and is marked $s\,a^L$, as indicated in the end and bottom-sectional views.

81. Bills of Material.—It is the practice of some companies to give at the right-hand end of the drawing a summary or bill of the materials that go into the construction of the member detailed. A typical illustration of such a bill is shown in Fig. 58. The outline of the bill is generally printed on the sheet, and all the draftsman need do is to fill it out. The line numbers given in the first column are also printed on the sheet. In the second column the draftsman letters the total number of pieces required for the total number of members to which the bill applies. Thus, if instead of one girder *G41*, the bill had applied to 4 girders *G41*, the number of pieces marked in the fourth line would have been 8, in the fifth line also 8, in the sixth line 4, etc. The remaining columns are self explanatory. Note, however, that in giving the shape of the member the inch marks are omitted. In the larger offices, the draftsman

need not fill out the bill beyond the column headed *Remarks*, because that is done by men specially designated for that purpose.

RIVETED COLUMNS

82. Plate-and-Angle Column.—The plate-and-angle column, composed of a web plate and four flange angles, with or without cover plates, is the type of riveted column most widely used in the construction of office and mill buildings. For the area of metal in its cross-section it is not so strong as other types of riveted columns, but it may be constructed with greater ease and it is of most convenient form for connecting other members to it. A detail drawing of a plate-and-angle column is shown in Fig. 59. The column shown is composed of four flange angles 5 in.$\times 3\frac{1}{2}$ in.$\times\frac{1}{2}$ in., one web plate 10 in.$\times\frac{1}{2}$ in., and two cover plates 12 in.$\times\frac{1}{2}$ in., which are riveted together in the same way as the component parts of a plate girder. As in the case of plate girders, the backs of the flange angles project $\frac{1}{4}$ inch beyond the edges of the web plate, so that while the depth of the plate is 10 inches, the distance back to back of flange angles is $10\frac{1}{2}$ inches.

83. Channel Column.—Next in importance to the plate-and-angle column is the channel column, composed of two channels and lacing bars or two channels and cover plates. In Fig. 60 is shown a detail drawing of a channel column composed of two channels 12 in.$\times$20.7 lb. and two cover plates 14 in.$\times\frac{5}{8}$ in. The channel column offers a more economic distribution of metal than the plate-and-angle column, but it is considerably more difficult to make connections to its sides. All rivets in the connections, except those which pass through the flanges of the channels, must be driven before the channels and plates are riveted together. All subsequent connections are made by means of long bolts which pass through the column shaft. Thus, the top angles *t b* are bolted by means of two $\frac{3}{4}$-inch diameter bolts 10 inches in length.

84. Methods of Detailing Columns.—In detailing columns it is best to draw them in vertical position as they appear in

the finished structure. The horizontal dimensions of the column and all details shown are drawn to scale, usually $\frac{3}{4}$ inch = 1 foot or 1 inch = 1 foot, but unless space permits, the length of the column need not be to scale. Office-building columns are usually constructed in two-story lengths, and they are finished at both ends so that they bear evenly on the base plate, column base, or section of column below, and provide even bearing for the section of column above. The principal dimension of the column is its length between finished ends.

The other important lines of reference are the levels of the finished floors, from which are located the details of the column. The finished floor lines are generally indicated by light lines; they are marked either by means of a number or capital letter indicating the floor, as *B* for basement, *1* for first floor, *2* for second floor, etc., inserted in a heavy circle as in Fig. 59, or by the floor numbers written above or below the floor lines as in Fig. 60. The dimensions between the finished ends of the column and the floor lines are given next to the dimension of the finished length of the column. The dimensions of the finished length of the column and the location of the floor lines are usually given in only one elevation view.

The next lines of dimensions to be considered are those that locate the tops of the beam and girder brackets or seat angles from the lower finished end of the column by means of extension dimensions in each elevation view. In Figs. 59 (*a*) and 60 (*a*), the third line of dimensions gives the distances from the backs of the base angles of the column to the backs of the seat angles for the support of 15-inch **I** beams framing into the column; the dimension *22′ 4″* is from the backs of the base angles to the backs of the seat angles for the beams of the second floor. Similarly, in the elevation views shown in (*b*), the first line of dimensions locates the backs of the seat angles for the support of 10-inch **I** beams from the backs of the base angles of the column.

The remaining important line of dimensions in each elevation view is that giving the spacing of the rivets in the column faces. The pitch of the rivets connecting the flange

angles to the web plate or to the cover plates in plate-and-angle columns, or the pitch of the rivets connecting the channels to the cover plates in channel columns, is generally made 4 diameters of the rivet in a distance equal to $1\frac{1}{2}$ times the greatest width of the member from the ends and opposite the connections of the beams or girders to the columns; the allowable maximum rivet spacing is used elsewhere, as provided in Art. **30.** Thus, in the columns shown in Figs. 59 and 60, the diameter of the rivets is $\frac{3}{4}$ inch and the rivet pitch is $4\times\frac{3}{4}$ in. $=3$ inches near the ends and opposite connections, and 6 inches elsewhere.

85. To represent the column properly on the drawing, it is necessary to show at least two elevation views; one bottom-sectional view, and one or more other views, showing plans of the connections provided for framing the beams and girders into the column, are frequently added. For the proper presentation of the various parts of the column detailed in Fig. 59, a side view is shown in (*a*), a front elevation in (*b*), a bottom-sectional view in (*c*), and a sectional view giving the location of the open holes in the top and seat angles for the beams framing into the column at each floor in (*d*). The details of the column in Fig. 60 are shown by means of the side views in (*a*) and (*c*), front elevation in (*b*), a bottom-sectional view in (*d*), a sectional view at the floor levels in (*e*), and a top view locating the holes in the cap in (*f*). The front elevation shown in (*b*) is of face *B*. Face *D* is not the same as face *B*, but is opposite to it, because if the column were turned around so as to present face *D* the brackets for the connection of the 15-inch **I** beams would appear on the right side of the column, or on the opposite side to that shown in (*b*). However, it is not necessary to draw another view for face *D* because the fact that the two views are opposite is made clear by the note, *Face D Opposite,* in (*b*). Had the two views been altogether unlike, another view to the right of (*c*) would have been drawn to show face *D*. Often one view is employed to show two faces which are not exactly alike or opposite, the variation between the faces being indicated by suitable notes.

For the guidance of the erectors, when the opposite faces of the column are not exactly alike it is customary to state on the drawing the direction in which one of the sides of the column

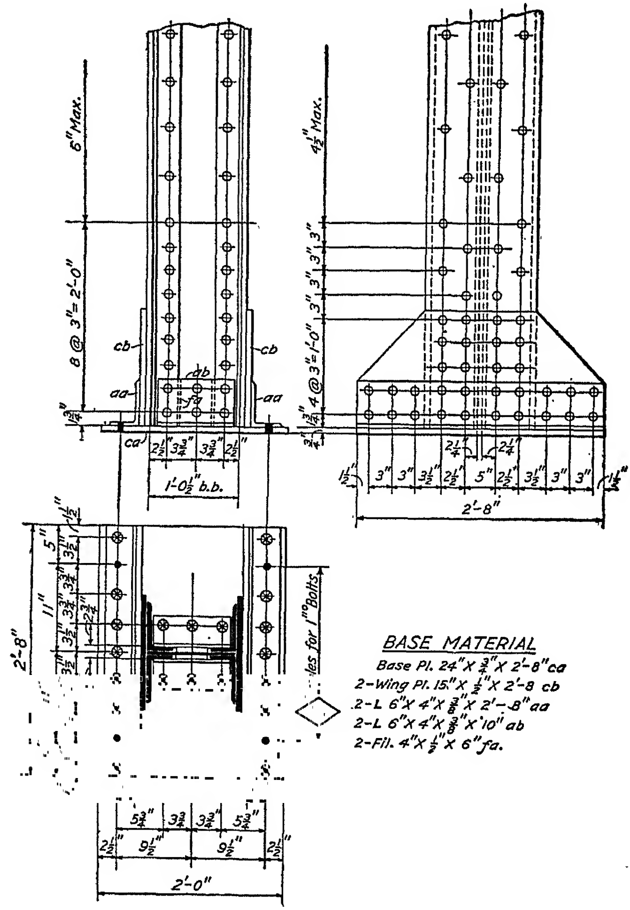
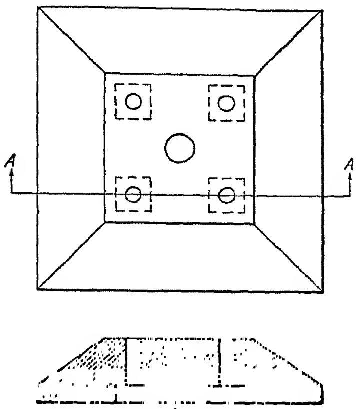


FIG. 61

faces. Thus, the note, *Face A North*, in Fig. 60, means that the column should be erected so that face *A* is approximately northward.

The assembling marks for the various details of the column and the bills of material are made in the same way as for girders.

86. Column Bases.—The loads from the columns are transferred to the soil by means of masonry piers, steel grillage footings, or reinforced-concrete spread footings. The columns of the warehouse shown in Fig. 10 are supported by means of grillage beams, while those of the shop building shown in Fig. 12 are supported by means of plain-concrete piers. To distribute the load from the column over a comparatively large area of footing, bases are generally provided. These bases consist of steel plates connected to the column by means of rivets countersunk on the bottom, as in the column shown on Plate 2, of rolled steel slabs bolted between the masonry piers and the base angles which are riveted to the end of the column, or of cast-iron slabs and pedestals bolted to the base angles of the column.



Section A-A

FIG. 62

In Fig. 61 are shown details of the end of a column with a riveted base, which is composed of a $\frac{3}{4}$-inch *base plate* fastened to the column by means of rivets countersunk on the bottom, two reinforcing plates known as *wing plates* or *gusset plates*, and two pairs of $6'' \times 4'' \times \frac{3}{8}''$ angles, which are used to connect the base plate to the wing plates and column. The end of the column is finished so that it bears evenly on the base plate. In a column of this type all dimensions are given from the finished end and not from the base plate. The holes in the base plate provided for connecting the column base to the masonry are generally made about $\frac{3}{8}$ inch larger than the diameter of the anchor bolts, to allow for slight inaccuracies in setting the bolts and to facilitate placing the column.

The columns shown in Figs. 59 and 60 are designed to rest on rolled-steel slab or cast-iron bases, When ordered in large quantities, rolled-steel slabs may be obtained from the rolling mills in thicknesses up to 12 inches and they may be advantageously used as column bases. In Fig. 10, the bases under the columns are rolled-steel slabs.

When cast-iron bases are used, solid cast-iron slabs are found economical when the required thickness of base does not exceed 4 inches; otherwise, cast-iron pedestals should preferably be used. A plan and sectional view of a cast-iron slab is shown in Fig. 62, while a plan and sectional view of a cast-iron pedestal is shown in Fig. 63.

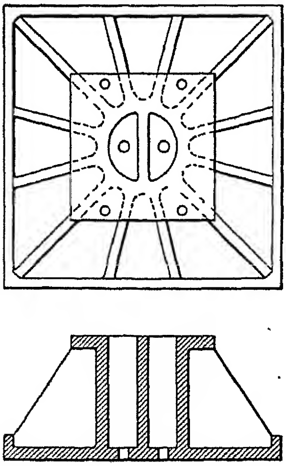


FIG. 63

87. Column Splices.—Columns should preferably be spliced above the floor line and as near to it as possible without interfering with the connections of the floor beams and girders to the columns. Usually the columns are spliced at a distance of 18 inches above the floor line, although shorter distances are often used, as in Figs. 59 and 60.

Plate-and-angle columns are generally spliced by means of plates riveted to the sides of the two portions of the column, as in Fig. 59. The function of these splice plates is to hold the column in line, it being assumed that the load from the upper section is transmitted to the lower by direct bearing of their finished ends. Columns composed of channels and cover plates cannot be conveniently spliced by means of plates only. Hence, splices similar to that shown in Fig. 60 are often employed. In addition to the two splice plates fastened to the sides by means of rivets passing through the flanges of the channels, a cap plate is used between the two sections, and the connection angles at the upper end of the

plan view and in cross-section in Fig. 11 of the text. The column is composed of four angles 6 in.×4 in.×$\frac{1}{2}$ in., a web plate 12 in.×$\frac{3}{8}$ in., and two cover plates 14 in.×$\frac{3}{8}$ in. The angles are riveted to the web so that their backs project $\frac{1}{4}$ inch beyond the edges of the web; hence, the distance back to back of angles is 1 foot 0$\frac{1}{2}$ inch, as given in Fig. 2 of the Plate. The bottom of the column is 7 inches below the basement floor and the splice line is 1 foot 6 inches above the second floor, the second floor being 14 feet 0 inch above the first floor, and the first floor 12 feet 6 inches above the basement floor. These floor lines are shown on the drawing and indicated within heavy circles by the letter *B*, for basement, and the numbers *1* and *2*, for the first and second floors, respectively. The finished length of the column between finished ends, or from the top of the steel slab on which it rests to the finished splice line, is 7 in.+12 ft. 6 in.+14 ft. 0 in.+1 ft. 6 in.=28 feet 7 inches.

89. After the main dimensions of the column have been established, it is necessary to locate the connections of the girders and beams to the column. According to Fig. 11 in the text, the backs of the top flange angles in the girders are 4 inches below the finished floor lines, and since the depth of the girders is 2 feet 6$\frac{1}{2}$ inches back to back of flange angles, the backs of the seat angles for the girders are 2 ft. 6$\frac{1}{2}$ in.+4 in. =2 feet 10$\frac{1}{2}$ inches below the floor lines. The backs of the seat angles are located by means of extension dimensions from the lower finished end of the column; for the seat angles at the first floor the dimension from the end of the column is 7 in. +12 ft. 6 in.−2 ft. 10$\frac{1}{2}$ in.=10 feet 2$\frac{1}{2}$ inches, while for the seat angles at the second floor it is 7 in.+12 ft. 6 in.+14 ft. 0 in. −2 ft. 10$\frac{1}{2}$ in.=24 feet 2$\frac{1}{2}$ inches. The open holes for the connection of the girders to the column may now be located and dimensioned.

According to Fig. 11, the tops of the 15″×60.8 lb. I beams which frame into the columns are 5 inches below the floor lines. The tops of the brackets on which they rest are therefore 1 ft. 3 in.+5 in.=1 foot 8 inches below the floor lines, as shown in Fig. 2 of the Plate. The extension dimension

to the top of the bracket at the first floor from the bottom of the column is 7 in. + 12 ft. 6 in. − 1 ft. 8 in. = 11 feet 5 inches, and to the top of the bracket at the second floor it is 7 in. + 12 ft. 6 in. + 14 ft. 0 in. − 1 ft. 8 in. = 25 feet 5 inches. Each bracket consists of one seat angle *b b*, two stiffener angles $k\ a^R$ and $k\ a^L$ ground to bear against the fillet of the seat angle, and one filler plate *d a* to fill the space between the stiffener angles and the flange angles of the column below the vertical leg of the seat angle. The two stiffener angles are opposite and not interchangeable because they are finished at one end only, and hence they are marked *R* (right) and *L* (left). The backs of the top angles *t a* are $\frac{1}{4}$ inch above the tops of the 15-inch I beams, or 1 foot $3\frac{1}{4}$ inches above the backs of the seat angles. The location of the holes in the top and seat angles for the connections to the top and bottom flanges of the 15-inch I beams and to the bottom flanges of the girders is shown in Fig. **3**, which is a cross-section taken at planes *A*–*A*.

The two $6'' \times 4'' \times \frac{3}{4}''$ base angles which are riveted to the lower end of the column have four $1\frac{3}{8}$-inch-diameter holes for bolting the column to the steel slab by means of 1-inch-diameter bolts. No bottom-sectional view need be drawn in this case, as the location of the holes is clearly given in the two elevations of the column.

90. The section of the column above the second floor is composed of four flange angles 6 in. × 4 in. × $\frac{1}{2}$ in. and one web plate 12 in. × $\frac{3}{8}$ in. Hence, the cover plates of the column shown are extended $2\frac{1}{2}$ inches beyond the second floor, and the splice plates *c a* are connected to the flange angles of the column. The splice plates *c b* are not riveted to the column but are shipped bolted. During erection these plates are removed, and after the upper portion has been put in place they are riveted to both portions. In a similar manner the top angles for the beam connections are shipped bolted to the column; they are removed before the beams are put in place, and are subsequently connected to the column and beams.

91. After the connections and the splice have been detailed, the pitch of the rivets in the various faces of the

column should be established. The gauges in the base angles, shown in Fig. **1**, are $1\frac{3}{4}$ and 3 inches. From the upper gauge line to the next line of rivets is 3 inches and beyond that line 6 alternate spaces of 3 inches are specified. The total distance from the bottom of the column to the end of the 3-inch spacing is $1\frac{3}{4}$ in. $+2\times3$ in. $+6\times3$ in. $=2$ feet $1\frac{3}{4}$ inches. The gauge in the seat angle *b a* is $2\frac{1}{2}$ inches, and the distance from the gauge line to the end of the 3-inch spacing is 10 ft. $2\frac{1}{2}$ in $-$(2 ft. $1\frac{3}{4}$ in. $+2\frac{1}{2}$ in.) $=7$ feet $10\frac{1}{4}$ inches; twenty alternate spaces at $4\frac{1}{2}$ inches and one space of $4\frac{1}{4}$ inches are therefore specified. The spacing of the open holes for the connection of the girder should match the spacing shown in Fig. **5**, because girder *G2* is connected to column *C4* in the same manner as girder *G1* is connected to the wall columns. The first line of holes is $1\frac{3}{4}$ inches above the bottom of the girder, or the top of the seat angle, and nine spaces of 3 inches are located beyond that line. To prevent possible distortion of the cover plates before the girders are connected, they are fastened to the flange angles by means of rivets which are countersunk on the near side. The distance from the top of angle *b a* to the first floor line is 2 feet $10\frac{1}{2}$ inches, and since the distance from top of the angle to the upper line of holes is $1\frac{3}{4}$ in. $+2$ ft. 3 in. $=2$ feet $4\frac{3}{4}$ inches, a space of 2 ft. $10\frac{1}{2}$ in. -2 ft. $4\frac{3}{4}$ in. $=5\frac{3}{4}$ inches remains. The distance from the first floor to the top of the seat angle *b a* at the second floor is 24 ft. $2\frac{1}{2}$ in. $-$ 13 ft. 1 in. $=11$ feet $1\frac{1}{2}$ inches, and from the upper line of holes in the girder at the first floor to the top of the angles at the second floor is 11 ft. $1\frac{1}{2}$ in. $+5\frac{3}{4}$ in. $=11$ feet $7\frac{1}{4}$ inches; the spacing shown may therefore be employed. The rivet spacing in the remainder of Fig. **1**, and in Fig. **2**, is arranged in a similar manner.

92. Details of Girder.—The girder detailed in Figs. **4**, **5**, **6**, **7**, and **8** is one of the wall girders *G1* in Figs. 10 and 11 in the text. It is composed of four flange angles 6 in. $\times4$ in. $\times\frac{7}{16}$ in., a web plate 30 in. $\times\frac{3}{8}$ in., and two cover plates 14 in. $\times\frac{3}{8}$ in., the top cover plate running the full length of the girder and the bottom cover plate 1 foot beyond the point where it is no longer necessary to help resist the stress in the flange. The

depth of the girder, back to back of flange angles, is $\frac{1}{2}$ inch more than the depth of the web, or 2 feet $6\frac{1}{2}$ inches.

The distance between the center lines of the columns into which the girder frames is 22 feet. The distance from the center line of the column to the outside of the cover plate is $6\frac{1}{4}$ in. $+\frac{3}{8}$ in. $=6\frac{5}{8}$ inches; allowing $\frac{1}{16}$ inch for erection clearance between the end of the girder and the face of the column, the distance from the center line of the column to the outside of the girder is $6\frac{5}{8}$ in. $+\frac{1}{16}$ in. $=6\frac{11}{16}$ inches. The total length of the girder, outside to outside, is, therefore, 22 ft. 0 in. $-2\times 6\frac{11}{16}$ in. $=20$ feet $10\frac{5}{8}$ inches.

93. The 15-inch I beams are connected to the stiffeners $s\,c^R$ and $s\,c^L$ of the wall girders by means of connection plates in the manner shown by the light lines in Figs. 7 and 8. Consequently, the distance from the center line of the beam to the back of the stiffener is one-half the thickness of the web, which according to Table IV is $\frac{5}{16}$ inch for a 15″ I 60.8 lb. The distance from the center line of the column to the center line of the first beam framing into the girder is 5 feet 6 inches, and hence the distance from the outside of the girder to the center line of that beam is 5 ft. 6 in. $-6\frac{11}{16}$ in. $=4$ feet $11\frac{5}{16}$ inches. The distance from the end of the girder to the back of the stiffener $s\,c^R$, to which the beam connects, is therefore 4 ft. $11\frac{5}{16}$ in. $-\frac{5}{16}$ in. $=4$ feet 11 inches; assuming a 2-inch gauge in the leg of that stiffener, the distance from the outside of the girder to the gauge line in the leg of the stiffener is 4 ft. 11 in. $+2$ in. $=5$ feet 1 inch. This distance will be broken up into two panels, 2 feet 4 inches and 2 feet 9 inches, respectively. The remaining distance to the center line of the girder is one-half of the total length of the girder less 5 feet 1 inch, or 10 ft. $5\frac{5}{16}$ in. -5 ft. 1 in. $=5$ feet $4\frac{5}{16}$ inches, which distance may be divided into two panels, 2 feet 9 inches and 2 feet $7\frac{5}{16}$ inches, respectively. The stiffeners at the middle of the girder will be placed so that their backs are $\frac{5}{16}$ inch to the left of the center line. The stiffeners in the part of the girder not shown are placed in exactly the same positions with respect to the center line of the girder as those in the part given, as indicated by the

note, *Girder symmetrical about C. L. except as shown at center.* The number of rivets in the end stiffeners is determined by the conditions of the design, and the rivet spacing in the intermediate stiffeners is usually made the same as in the end stiffeners.

94. After the stiffeners have been properly located, the rivet spacing in the flange angles and cover plates may be determined. It is customary to vary the pitch in the flange angles in each panel in accordance with the conditions of the design. Thus, in the first panel the permissible pitch is $2\frac{3}{4}$ inches, in the second panel $3\frac{1}{4}$ inches, in the third 4 inches, and in the fourth 5 inches. The Multiplication Table for Rivet Spacing, on pages 328 to 330, inclusive, in *Smoley's Tables* may be used to advantage in dimensioning the rivet spacing in the various panels.

In the first panel, the spacing of the first line of rivets is the standard gauge in a 4-inch leg, or $2\frac{1}{2}$ inches. The next line of rivets should be sufficiently far away from the first to allow proper driving clearance from the leg of the angle; a 3-inch spacing is therefore chosen. The remaining distance to the gauge line in the first intermediate stiffener is 2 ft. 4 in. $-(2\frac{1}{2}$ in.$+3$ in.$)=1$ foot $10\frac{1}{2}$ inches. The number of $2\frac{3}{4}$-inch spaces that may be used in the available space can be found in the Multiplication Table for Rivet Spacing. Locate in the first column on page 328 the number $2\frac{3}{4}$ and follow along the horizontal row in which that number is located until the numbers *1–7¼* and *1–10*, which are nearest to the available 1 foot $10\frac{1}{2}$ inches, are reached. At the heads of the columns in which the numbers are found, read the number of $2\frac{3}{4}$-inch spaces to which they correspond, namely, 7 and 8, respectively. It is evident that the seven spaces at $2\frac{3}{4}$ inches are more suitable, because the space left is 1 ft. $10\frac{1}{2}$ in. -1 ft. $7\frac{1}{4}$ in. $=3\frac{1}{4}$ inches, which is enough to provide proper driving clearance for the rivets nearest to the outstanding leg of the stiffener.

The length of the second panel is 2 feet 9 inches and the permissible rivet pitch is $3\frac{1}{4}$ inches. According to the Multiplication Table, nine spaces at $3\frac{1}{4}$ inches are equal to 2 feet

$5\frac{1}{4}$ inches, and ten spaces to 2 feet $8\frac{1}{2}$ inches. The former spacing leaves a distance of 2 ft. 9 in. $-$ 2 ft. $5\frac{1}{4}$ in. $= 3\frac{3}{4}$ inches from the gauge line of the second pair of intermediate stiffeners, which provides ample driving clearance for the rivets adjacent to the outstanding leg of the stiffener, and hence that spacing is adopted.

The length of the third panel is also 2 feet 9 inches and the permissible rivet pitch is 4 inches. If seven spaces at 4 inches are adopted, the space left to the gauge line of the third pair of intermediate stiffeners is 2 ft. 9 in. $-$ 2 ft. 4 in. $=$ 5 inches, which is satisfactory.

The length of the fourth panel is 2 feet $7\frac{5}{16}$ inches and the permissible spacing is 5 inches. The backs of the stiffeners at the middle of the girder are $\frac{5}{16}$ inch to the left of the center line of the girder, and hence the gauge line of the stiffeners is 2 in. $-\frac{5}{16}$ in. $= 1\frac{11}{16}$ inches to the right of the center line. The girder is made symmetrical about its center line, except for the line of rivets in the middle stiffeners. In order that the spacing of rivets in the flanges in the fifth panel may be the same as in the fourth panel, the rivets adjacent to the stiffeners will be spaced $1\frac{11}{16}$ inches to the left of the center line. The distance left for the 5-inch spacing is therefore 2 ft. $7\frac{5}{16}$ in. $- 1\frac{11}{16}$ in. $=$ 2 feet $5\frac{5}{8}$ inches, of which distance five spaces at 5 inches require 2 feet 1 inch, leaving $4\frac{5}{8}$ inches for the first space in the panel.

95. The rivets in the top and bottom cover plates are so arranged that part of the templet for the top cover plate may be used for the bottom cover plate; in other words, the rivets in the two cover plates are made exactly opposite. At the ends of cover plates the rivets should be spaced 4 diameters apart for a distance equal to about one and one-half times the width of the plate. In this case this need only apply to the bottom plate, since the top plate projects well beyond the point where it is no longer necessary to resist stress.

In locating the rivets in the cover plates, it is best to tie them in with the gauge lines of the stiffener angles, because it is thus easier to prevent placing the rivets adjacent to the stiff-

eners too close to the outstanding leg for driving. In this case, a row of rivets is placed opposite the rivets in the first, second, and third pairs of intermediate stiffeners, and the rivets near the central stiffeners are otherwise tied in. A spacing of 4 inches being adopted, in the first panel, six spaces at 4 inches occupy 2 feet 0 inches, leaving 4 inches to be divided into one $1\frac{3}{4}$-inch space and one $2\frac{1}{4}$-inch space.

In the second panel the spacing is largely governed by the requirements of the bottom plate, which projects 6 ft. 4 in. $-$(2 ft. 9 in.$+$2 ft. $7\frac{5}{16}$ in.) $=11\frac{11}{16}$ inches to the left of the gauge line in the second intermediate stiffener. In that space one 4-inch space to the left of the row in line with the gauge line in the stiffener and two 3-inch spaces may be assumed, leaving an edge distance for the plate of $11\frac{11}{16}$ inches$-$(4 in.$+2\times3$ in.) $=1\frac{11}{16}$ inches. The remaining space in the second panel is 2 ft. 9 in.$-$10 in.$=$1 foot 11 inches, and the allowable pitch in that space is 6 inches; hence, three spaces at 6 inches are specified, leaving a 5-inch space at the beginning of the panel.

In the third panel three more spaces at 3 inches are adopted to agree with the requirements for the bottom cover plate. The space left is 2 ft. 9 in.$-$9 in.$=$2 feet 0 inches, which supplies four spaces at 6 inches. In a similar manner the spacing in the fourth panel is easily arranged.

96. After the details and dimensions of the girder have been completed, it is necessary to state or list the sizes of the pieces entering into its construction. In this case, assembling marks are given to all parts except the main material of the girder, and the sizes of all pieces are listed in the bill of material above the title of the drawing.

Since the girder is 2 feet $6\frac{1}{2}$ inches back to back of flange angles and the thickness of the legs of the flange angles is $\frac{7}{16}$ inch, the length of the stiffeners is 2 ft. $6\frac{1}{2}$ in.$-2\times\frac{7}{16}$ in.$=$2 feet $5\frac{5}{8}$ inches. The length of the $\frac{7}{16}$-inch fillers between the edges of the vertical legs of the flange angles and under the stiffeners is 2 ft. $6\frac{1}{2}$ in.$-(2\times4$ in.$+2\times\frac{1}{4}$ in.)$=$1 foot 10 inches. The end stiffeners are marked *s a*, and the fillers under them *d b* since there are two rows of rivets through them. The first

and third pairs of intermediate stiffeners are marked *s b*, while in the second and fourth pairs one stiffener has open holes for beam connections, and hence it is marked sc^R, and the other *s b*. All fillers under the intermediate stiffeners being interchangeable, they are given the mark *f a*.

97. Directions for Drawing Plate 3.—Commence drawing Plate 3 by laying off the center line of Fig. 1 at a distance of $2\frac{1}{2}$ inches from the left-hand border line. Along that center line lay off the end of the column $1\frac{1}{2}$ inches from the lower border line, and the splice line $1\frac{1}{4}$ inches from the upper border line. Draw the basement floor line 7 inches, to the scale of $\frac{3}{4}$ inch = 1 foot, above the end of the column, the first floor line $4\frac{1}{2}$ inches, full size, above the basement floor line, and the second floor line 1 foot 6 inches, to scale, below the splice line. Using the scale of $\frac{3}{4}$ inch = 1 foot, draw the outline of the column and the various vertical rivet lines, and indicate the web plate and angles by means of dotted lines drawn near the ends of the column. Draw the base angles at the lower end of the column. From the floor lines lay off to scale the connections for the girders. At the first and second floors, detail these connections and the splice as shown on the sample Plate and as previously described. Draw the dimension lines in the same relative positions as on the sample Plate, and specify the sizes of the various pieces.

Draw the center line of Fig. 2 at a distance of $2\frac{5}{8}$ inches from the center line of Fig. 1. Draw the outline of the column and the side views of the various connections detailed in Fig. 1 to scale. Locate to scale the connections for the 15-inch I beams from the floor lines; detail these connections and the splice plates *c b* as shown. Lay off the rivet spacing, and complete the view.

To finish the details of the column, Fig. 3 should now be drawn. Lay off the vertical axis of the view $2\frac{1}{2}$ inches from the center line of Fig. 2 and the horizontal axis 5 inches from the lower border line, and complete the view as shown.

98. In drawing the details of the girder, is is best to begin with the elevation, Fig. 4. Commence by drawing the

center line of the girder $\frac{5}{8}$-inch from the right-hand border line, and the backs of the top flange angles 3 inches from the upper border line. Draw the end of the girder 10 feet $5\frac{5}{16}$ inches, to the scale of $\frac{3}{4}$ inch = 1 foot, from the center line, and the backs of the bottom flange angles 2 feet $6\frac{1}{2}$ inches from the backs of the top flange angles. Draw the edges of the cover plates and of the outstanding legs of the flange angles, and the gauge lines in the flange angles. Detail the end stiffeners and filler plates, and draw the end view, Fig. 5, the center line of which should be located $1\frac{5}{8}$ inches from the end of the girder. After Fig. 5 has been drawn to scale, proceed with Fig. 4, by locating the gauge lines of the intermediate stiffeners and detailing those stiffeners to correspond with the end stiffeners. Draw the edges of the vertical legs of the flange angles and indicate the ends of the fillers by dotted lines. Finally, complete Fig. 4 by establishing the rivet pitch in the various panels.

Fig. 6 and Fig. 7 should be worked up at the same time, because the same dimensions apply to the top view and the bottom-sectional view. Begin Fig. 6 by laying off the center line 1 inch from the upper border line. Draw the outline of the top cover plate, show by dotted lines the flange angles, web plate, and stiffener angles, and draw the gauge lines. Now lay off the center line of Fig. 7 at a distance of $1\frac{1}{2}$ inches below the bottom of the girder, draw the web plate, flange angles, and cover plate, and show the gauge lines. Indicate the stiffener angles in section, which need not be cross-hatched. At the second pair of intermediate stiffeners, draw, in light lines, a bottom-sectional view of the connection of the 15″ I 60.8 lb. to the stiffener $s\,c^R$. Finally, arrange the rivet pitch in the top and bottom cover plates as previously described and complete the views.

To draw the Section *B–B* shown in Fig. 8, draw the vertical axis $5\frac{1}{2}$ inches from the right-hand border line, and the backs of the bottom flange angles 3 inches from the lower border line. Complete the cross-section in heavy lines and draw the 15-inch I beam and the plate connecting it to the stiffener $s\,c^R$ in light lines.

99. Directly above the title draw the lines for the bill of material. Draw the upper heavy horizontal line 5 inches from the lower border line, the second heavy horizontal line $\frac{1}{2}$ inch below, and under that line draw nine light horizontal lines $\frac{1}{4}$ inch apart. Now draw the vertical heavy and light lines: the column headed *LINE* is $\frac{3}{8}$ inch wide; the column headed *NO. PCS.* is $\frac{5}{8}$ inch wide; the column headed *SHAPE* is $1\frac{1}{2}$ inches wide and is divided into four columns by vertical lines $\frac{3}{8}$ inch apart; the column headed *LENGTH* is 1 inch wide and is divided into a column headed *FT.*, $\frac{3}{8}$ inch wide, and a column headed *IN.* $\frac{5}{8}$ inch wide; the remaining space is for the column headed *ASSEMBLING MARK.* Letter the headings for the different columns and fill out the bill as shown on the sample sheet.

Letter the notes and title and complete the plate.

DETAILS OF ROOF TRUSSES

PRELIMINARY CONSIDERATIONS

100. Parts of Roofs.—The roofs of buildings are composed of the roof covering and its supports. The roof covering is constructed of various materials, such as wood, corrugated steel, concrete, tile, gypsum, slate, tin, etc. The supports for the roof covering of office buildings are generally beams supported on columns. In shop buildings or in other structures where the roof covering is to be supported over long spans without the use of intermediate supports, *purlins* and *trusses* are employed.

Fig. 65 is a perspective of the roof of the shop building shown in Fig. 12. The roof covering of the building is composed of a reinforced-concrete slab *a*, covered with some roofing material *b* which helps make it waterproof; it is supported by means of horizontal beams *p*, commonly known as *purlins*, which rest on the trusses *t*. In this case the purlins are steel channels, but they may also be **I** beams, tees, zees, or wooden beams.

The steel trusses are supported either by masonry walls, as in Fig. 65, or by steel columns.

101. Roof Trusses.—When loads are to be supported over long spans, it is often found that instead of using structures with solid webs, such as plate girders, greater economy may be obtained by employing structures in which the flanges are connected by several inclined members. In Fig. 66 (*a*) is shown a plate girder and in (*b*) a jointed or framed structure designed to serve the same function in the building. A framed or jointed structure which is designed to act as a beam is commonly known as a *truss*. Whenever the distance between the outside walls of a building exceeds 30 feet, and there are no intermediate walls or columns, the roof of the building is generally supported by means of trusses, known as *roof trusses*.

In order to obtain rigidity, the members of trusses are arranged in a series of triangles, because the triangle is the only geometrical figure that cannot be changed in shape without altering the length of one or more of its sides. The points at which two or more members of the truss meet, as at *j* in Fig. 66 (*b*), are called *joints*. When the loads that come on trusses are applied at the joints, as in Fig. 65 where the purlins carrying the roof covering are supported at the joints *j* of the truss, the members of the truss are subjected to direct stresses, either tension or compression. If, however, the loads are applied between joints, as is often the case, the members supporting those loads are subjected to bending stresses in addition to the direct stresses while the other members are subjected to direct stresses only.

When the general construction of a roof truss is to be shown, it is most convenient to employ a *skeleton diagram*, in which the members of the truss are indicated by single lines. Thus, the truss in Fig. 12 (*b*) is represented by means of a skeleton diagram. Frequently, the function of the members of the truss is indicated on the skeleton diagrams, as in Fig. 67, where heavy lines are employed to represent members that are in compression, light lines to represent members that are in tension, and dotted lines to represent members that normally take no stress but are inserted mainly to make the truss more rigid.

The truss shown in Fig. 67 is known as a *Fink truss*. It is widely used in mill-building construction.

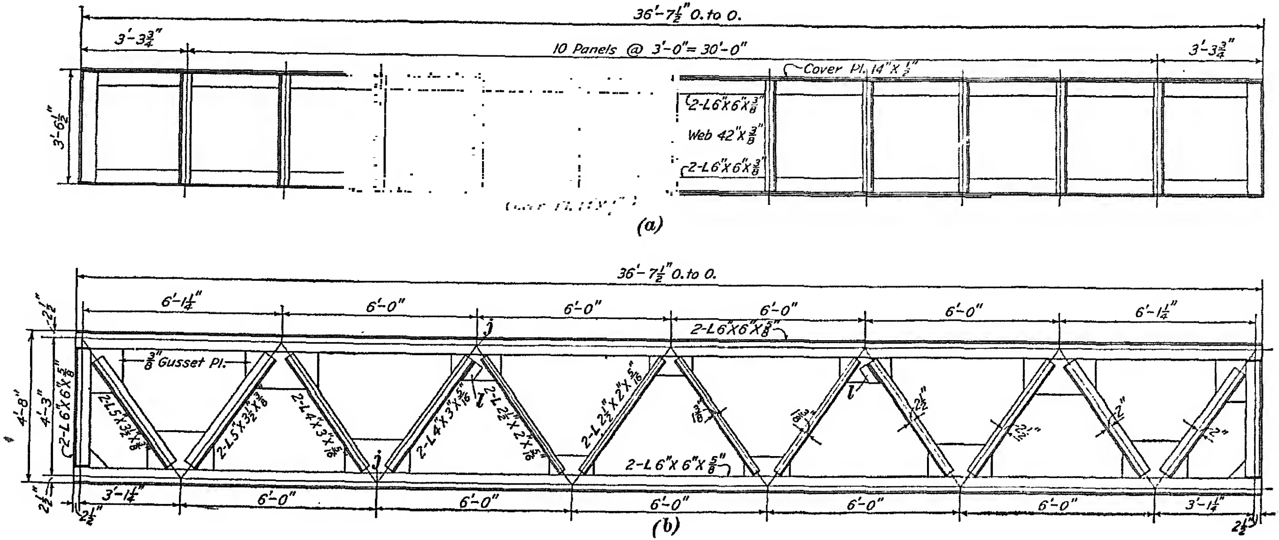

36'-7½" O. to O.
3'-3¾"
10 Panels @ 3'-0" = 30'-0"
3'-3¾"
Cover Pl. 14" X ½"
3'-6½"
2-L6"X6"X⅜"
Web 42"X⅜"
2-L6"X6"X⅜"
(a)
36'-7½" O. to O.
6'-1¼"
6'-0"
6'-0"
6'-0"
6'-0"
6'-1¼"
2-L6"X6"X⅝"
⅜" Gusset Pl.
2-L5"X3½"X⅜"
2-L5"X3½"X⅜"
2-L4"X3"X5/16"
2-L4"X3"X5/16"
2-L2½"X2"X5/16"
2-L2½"X2"X5/16"
2-L6"X6"X⅝"
j
j
l
l
4'-8"
4'-3"
2-L6"X6"X⅝"
2½"
3'-1¼"
6'-0"
6'-0"
6'-0"
6'-0"
6'-0"
3'-1¼"
2½"
2½"
2"
(b)

FIG. 66

102. Principal Parts and Dimensions of Roof Trusses. The principal parts of a roof truss, as indicated in Fig. 67, are its *top chord t* and *bottom chord b*, which are connected by means of the *web members w*. Web members which are in tension

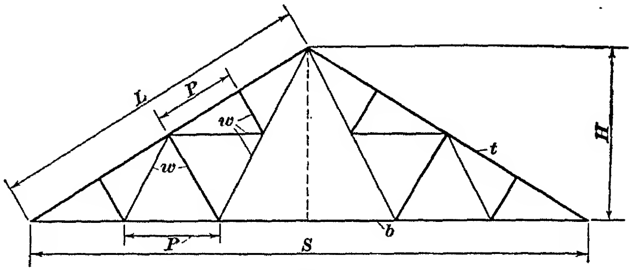


FIG. 67

are often called *ties* and those which are in compression are called *struts*. The space *P* between two consecutive joints in the top or bottom chord is known as a *panel* of the truss, and a joint is often referred to as a *panel point*. The space between two consecutive trusses is known as a *bay*.

The principal dimensions of a roof truss are its *span S*, *height* or *rise H*, and the *length of the top chord L*. In symmetrical roof trusses the ratio of the rise to the span is known as the *pitch of the truss*. This pitch is usually expressed as a fraction. Thus, when the rise is 10 feet and the span 40 feet, the pitch is $\frac{1}{4}$.

CONSTRUCTION OF ROOF TRUSSES

103. Composition of Truss Members.—The top chord is usually made up of two angles riveted side by side, with a series of separators between them, the rivets passing through the separators. As illustrated in Fig. 68, the separators are circular plates, commonly known as *washers*, which are of the same thickness as the distance between the angles, with a hole in the center $\frac{1}{16}$ inch larger than the diameter of the rivet shank. In Fig. 69 is shown the construction of a truss for a mill building. The top chord of that truss consists of two angles $3\frac{1}{2}$ in.$\times 2\frac{1}{2}$ in.$\times \frac{3}{8}$ in. fastened

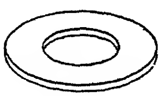


FIG. 68

together by means of stitch rivets and washers. When the top chord resists bending in addition to compression, it is often found best to construct it of two angles and a plate, as in Fig. 70.

The bottom chord is usually made up of two angles fastened together by means of rivets and washers, as in Fig. 69. However, when the bottom chord is to support a hoist or some other load that will tend to deflect it, two channels riveted together

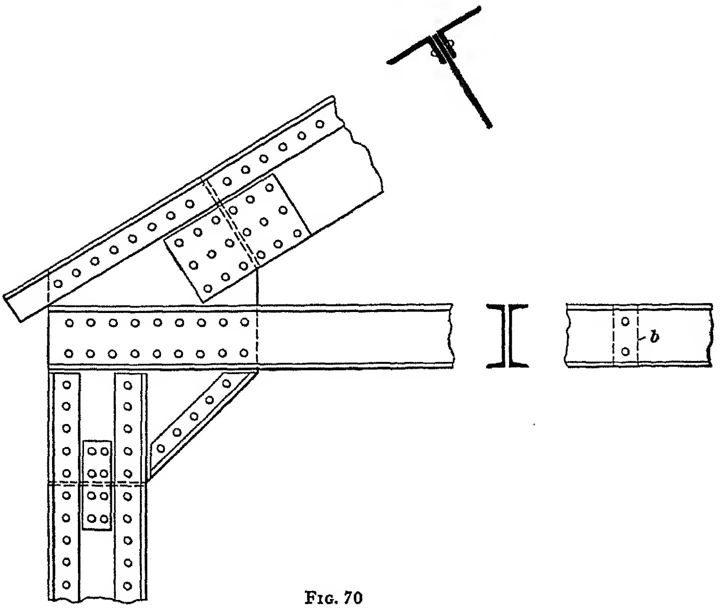


FIG. 70

back to back are often employed. The separators used for channels are usually $2\frac{1}{2}$ inch bars, as *b* in Fig. 70.

The web members are generally made up of either a single angle or two angles, depending on the stress in the member. Thus, in Fig. 69, the tie *t* at the middle of the truss and the two short struts *s* are single angles, while the other web members are composed of two angles.

104. Gusset Plates.—The various members of the truss are connected by means of plates called gusset plates, which

are inserted between the vertical legs of the members that are composed of two angles and are riveted to the back of single-angle members. The shape of the gusset plate depends upon the number and arrangement of the rivets in the members. Good practice demands that gusset plates be proportioned so that they may be cut from the smallest rectangular plate with as few cuts as possible, in order to avoid waste of metal and labor in cutting. The size of gusset plate specified on drawings is the size of the smallest rectangular plate from which it may be cut; the width of the gusset plate, or the first dimension given, is usually the standard width of the rectangular plate.

In heavy trusses, where the number of rivets in the members is large, the sizes of the gusset plates may be reduced by riveting *lug angles* to the outstanding legs of the angles composing the members and connecting these lug angles to the gusset plates. In Fig. 66 and at the end of the bottom chord in Fig. 69, lug angles *l* are employed in order to reduce the size of the gusset plates. Some engineers specify the employment of lug angles for truss members which require four or more rivets at their connections, because the stress carried in all parts of the member is thus transmitted most efficiently at the joint.

105. Rivets in Members.—The rivets that connect a single-angle member to a gusset plate are in *single shear*, because the tendency to shear them is only at the plane between the back of the angle and the gusset plate. On the other hand, the rivets that connect a member composed of two angles to a gusset plate inserted between the two angles are in *double shear*, the tendency to shear them being at the two planes between the backs of the angles and the gusset plate. The total safe stress that a rivet can transmit without shearing is known as its *shearing value*. The shearing value of a rivet in single shear, or the *single-shearing value* of a rivet, is equal to the cross-sectional area of the rivet multiplied by the safe unit shearing stress; the shearing value of a rivet in double shear, or the *double-shearing value* of a rivet, is twice

the single-shearing value. If the safe unit shearing stress is 12,000 pounds per square inch for shop rivets and 10,000 pounds per square inch for field rivets, which are commonly used values, the single-shearing value of a $\frac{3}{4}$-inch shop rivet is $.7854 \times (\frac{3}{4})^2 \times 12{,}000 = 5{,}300$ pounds, and its double-shearing value is $2 \times 5{,}300 = 10{,}600$ pounds; the single-shearing value of a $\frac{3}{4}$-inch field rivet is $.7854 \times (\frac{3}{4})^2 \times 10{,}000 = 4{,}420$ pounds, and its double-shearing value is 8,840 pounds.

Another value to be considered in the design of rivets is the total bearing stress of the gusset plate on the rivet, known as the *bearing value* of the rivet. The bearing value of a rivet is equal to the product of the thickness of the plate pressing against it, the diameter of the rivet, and the safe unit bearing stress. The safe unit bearing stress is usually twice the safe unit shearing stress. If the safe unit bearing stress is 24,000 pounds per square inch for shop rivets and 20,000 pounds per square inch for field rivets, and the thickness of the gusset plate is $\frac{3}{8}$ inch, then the bearing value of a $\frac{3}{4}$-inch shop rivet is $\frac{3}{8} \times \frac{3}{4} \times 24{,}000 = 6{,}750$ pounds, and the bearing value of a $\frac{3}{4}$-inch field rivet is $\frac{3}{8} \times \frac{3}{4} \times 20{,}000 = 5{,}625$ pounds.

The value in bearing or shear which gives the least strength of the rivet, is known as the *critical value* of the rivet. Usually, in members composed of a single angle, the single-shearing value of the rivet is the critical value, while in members composed of two angles the bearing value is the critical value. The number of rivets required at each end of a member to connect it to the gusset plate is determined by dividing the stress in the member by the critical value of a rivet.

106. At intermediate joints, such as joint E in the top chord of the truss in Fig. 69, joint D in the bottom chord, and joint F in member $B\,C$, the number of rivets in the continuous member is determined by the difference between the stresses in the member on both sides of the joint. Thus, if the stress in the bottom chord is 38,000 pounds in tension to the left of joint D, and 32,000 pounds in tension to the right of the joint, the number of rivets in the chord at the joint should be provided for a stress of $38{,}000 - 32{,}000 = 6{,}000$ pounds.

The required number of rivets is sometimes determined b the designer and specified on the design drawing in the manne indicated in the circles in Fig. 71 for the truss shown in Fig 69. Often only the stresses in the members are indicated by th designer, and the number of rivets is determined by the detailer Not less than two rivets should be used in each connection of a member regardless of the stress in the member. At the end of members the least number required should be provided, but at intermediate joints it may be found necessary to use mor rivets for the sake of appearance or convenient spacing Thus while the number of rivets required in the top chord a

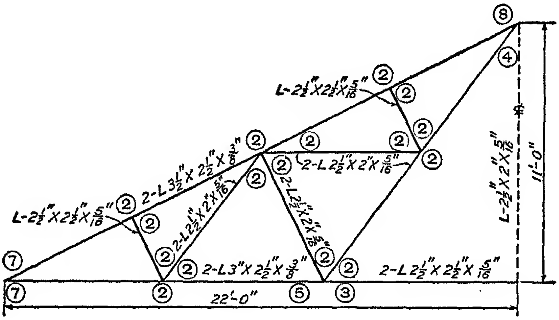


FIG. 71

E in Fig. 69 is two, the number actually used is five. However, at the ends of the various members the required numbe has been used throughout.

107. Working Lines.—Theoretically, the truss member should be laid out so that their center-of-gravity lines coincid with the lines of the skeleton diagram of the truss and intersect at a point at each joint. However, for all practica purposes the members may be laid out so that their rivet line coincide with the lines of the diagram and meet at a point a each joint, which facilitates considerably the detailing o the truss. These rivet lines constitute the *working lines* of th truss, and their intersections the *working points*. When th leg of the angle composing the member has two rivet lines the one nearer to the back of the angle is chosen as the workin line. In laying out the truss, the working lines are laid ou

first and from these lines and their intersections are laid out the members and details of the truss. All dimensions shown on the truss are tied in with the working lines and working points, as will be shown later.

108. Purlins.—Purlins are made of channels, **I** beams, zees, tees or angles. The shape most commonly used is the channel. For heavy roof covering or wide bays, **I** beams may be employed more advantageously, while for light construction angles may be used. Zees and tees are seldom employed in modern roof construction, although they were formerly used very extensively.

As shown in Fig. 69, the purlins rest on the top chord of the truss and are connected to it by means of angle clips which are bolted to the webs of the purlins and to the outstanding legs of the chord angles. When the depth of channel purlins is 8 inches or over, the bottom flanges of the channels are also bolted to the legs of the chord angles.

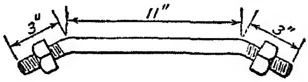


Fig. 72

To stiffen the purlins laterally and to prevent excessive sag in them, one or two rows of *sag rods* are employed. These sag rods are of either $\frac{3}{4}$-inch or $\frac{5}{8}$-inch diameter and are threaded at both ends; they pass through the webs of two adjacent purlins and are securely bolted at the ends in the same manner as tie rods in floors. The sag rods at the peak of the truss are bent at the ends as in Fig. 72.

109. Bracing.—In order to stiffen the roof of the structure so that it will safely resist the effect of high winds or vibration due to machinery, it is necessary to provide bracing between consecutive trusses in the end bays and in one or more intermediate bays of the building. Such bracing is provided in the planes of the top chords and in the plane of the bottom chords, as shown in Fig. 73, where a perspective of the steelwork in the planes of the top chords of the trusses in the roof of a building is shown in (*a*) and a perspective of the steelwork in the plane of the bottom chords is shown in (*b*). The top-chord bracing members *b* are round rods which run under the

purlins *p* and are connected to the outstanding legs of the top-chord angles of the trusses *t* by means of angle clips. The connection of the bracing rods to the top chord is shown in Fig. 69 (*c*). The bracing in the top chord, shown in Fig. 73 (*a*), is in the end bays and in the middle bay only, no cross-bracing being provided in the other bay. A ridge strut *r*, composed of two angles riveted back to back and running the full length of the building, is connected to the gusset plate at the peak of each truss, as *r* in Fig. 69 (*a*). When no ridge strut is used, the purlins at the peak are relied on to carry its stress in addition to supporting the roof covering. Longer clip angles

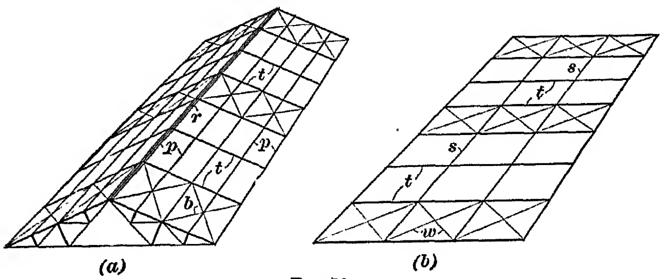


FIG. 73

with more bolts are then provided to connect the purlins to the trusses, as will be shown later.

The bottom-chord bracing members consist of one or two angles which are connected to the bottom chord by means of gusset plates in the manner shown in Fig. 69 (*b*). The struts in the braced bays consist of two angles riveted back to back. In the unbraced bays are run the ties, *u* in Fig. 69 (*b*) or *s* in Fig. 73 (*b*), which are usually single angles.

110. Masonry Bearing Plates.—When the ends of the truss are supported by a masonry wall or pilaster, as in Fig. 65, it is necessary to provide masonry bearing plates to distribute the load from the truss over a sufficiently large area of masonry so that the pressure per square inch will not exceed the allowable value. As illustrated in elevation in Fig. 74 (*a*) and in plan in (*b*), two plates of equal size and thickness are proportioned for that purpose, and employed as previously

explained for a girder supported by a masonry pier. The upper plate, or *sole plate*, is riveted to the end of the bottom chord by means of rivets countersunk on the bottom, while the lower plate, or *masonry plate*, is shipped loose. The two plates are anchored to the masonry by means of anchor bolts.

111. Fixed and Free Ends.—To provide for expansion and contraction of the truss with varying temperatures, the holes *h* in the sole plate for the anchor bolts are slotted at one end of the truss so that the sole plate can slide longitudinally over the masonry plate if necessary, the bottom of the sole plate and the top of the masonry plate being planed. The end of the truss that is firmly fixed to the masonry is known as the *fixed end*, while the other end which is free to move with the expansion and contraction of the truss is known as the *free end*.

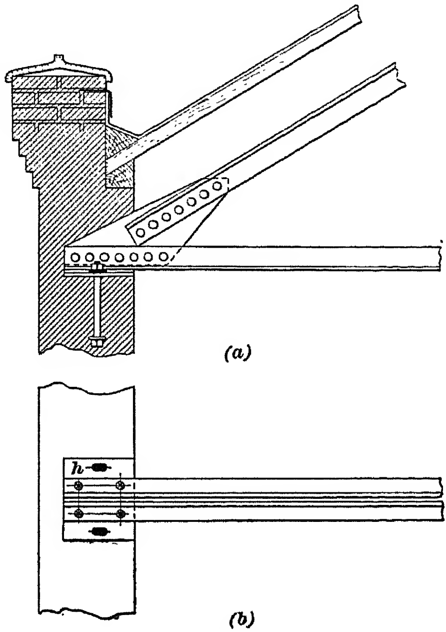


FIG. 74

In light trusses of comparatively short span, both ends are generally fixed to the masonry. In trusses of medium weight and span, as the truss shown in Fig. 69, provision for expansion and contraction of the truss with varying temperatures is best made by means of sliding plates. In heavy trusses of long span, the vertical loads on the end supports are large, and if sliding plates were employed at the free end of the truss they would be so pressed together that sliding of one plate over the other would be accomplished with great

difficulty. To facilitate the longitudinal movement of the truss, steel rollers are sometimes introduced between the two plates. In Fig. 75 are shown an end view (*a*) and side view (*b*) of the free end of a roof truss in which rollers are employed. The end of the roof truss is hinged to a steel shoe *s* by means of a pin *p*, and the shoe rests on the rollers *r* which are free to roll over the masonry plate *m* with the contraction and

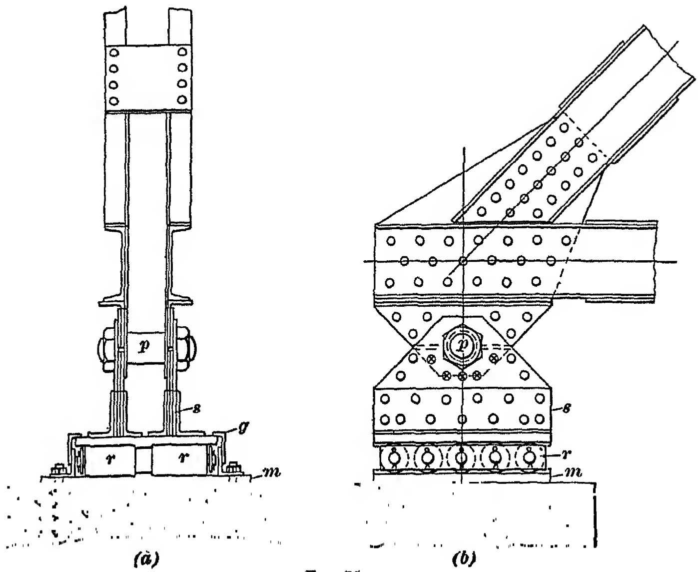


FIG. 75

expansion of the truss. In the view shown in (*b*) the guard *g*, shown in (*a*), is removed.

112. Shipment of Trusses.—Small trusses, like those shown in Fig. 65, are usually riveted up entirely in the shop. Larger trusses cannot be shipped in one piece, the maximum height of truss that can be transported by rail being about 10 feet 6 inches. Hence, the larger trusses are usually shipped in sections which are assembled on the job and erected in place. The truss shown in Fig. 69 would be shipped in two large sections and two single members: the section *A B C* and its corresponding section in the opposite half of the truss, the tie

t and the part c of the lower chord. It is for that reason that open holes are shown at the ends of members t and c and at the ends of the members of the other half of the truss which connect to the peak plate. When trusses are exported to foreign countries by steamship, it is most convenient to ship all members loose, or "knocked down."

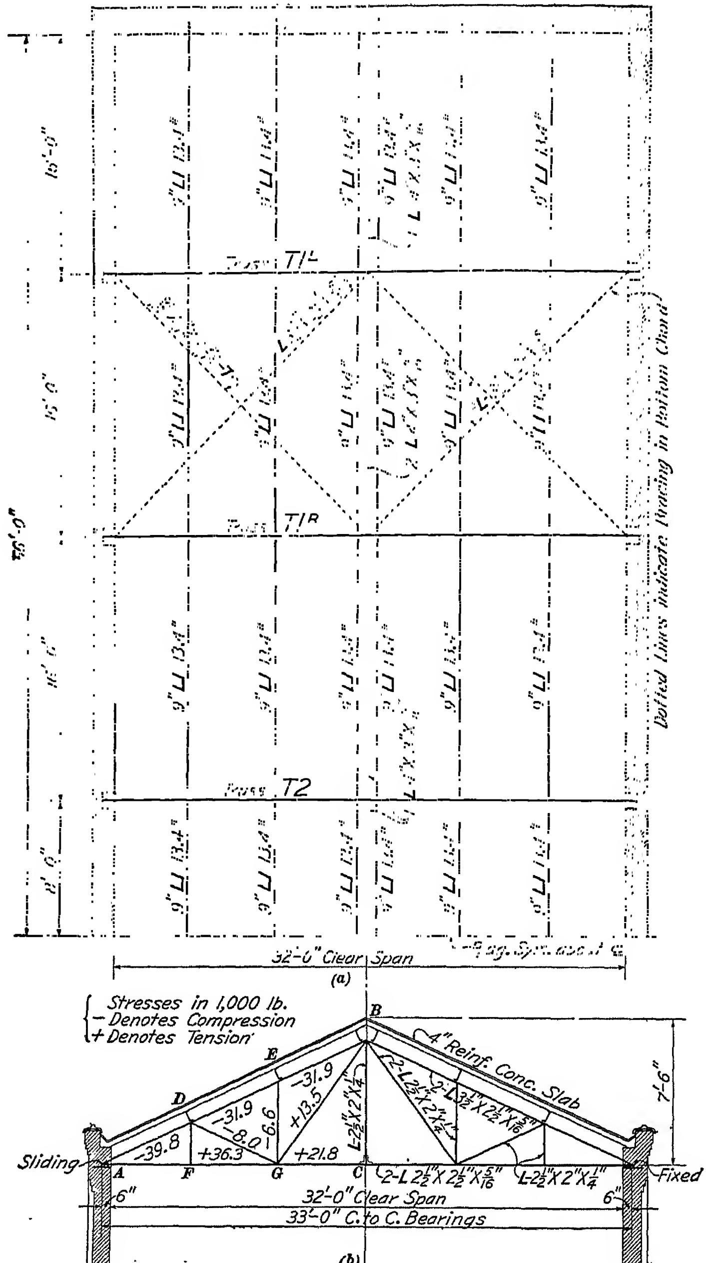
PLATE 4: DETAILS OF ROOF TRUSS

113. Lengths and Bevels of Truss Members.—In Plate 4, Details of Roof Truss, are given the details of the trusses of the roof shown in perspective in Fig. 65 and in plan and elevation in Fig. 76. Before the truss is laid out, it is best to compute the lengths between working points, and the bevels of the various members, on some such diagram as that shown in Fig. 77. The lengths and bevels should be determined to the nearest sixteenth of an inch by the aid of *Smoley's Tables*.

The rise BC of the truss being 7 feet 6 inches and the half-span AC being 16 feet 6 inches, the length AB of the top chord is the square root of the sum of the squares of 7 feet 6 inches and 16 feet 6 inches, which may be found by *Smoley's Tables* as follows:

$$
\begin{array}{lll}
\log BC & = \log\ 7 \text{ ft. } 6 \text{ in.} & = 0.87506 \\
\log AC & = \log\ 16 \text{ ft. } 6 \text{ in.} & = \underline{1.21748} \\
\log \tan A & = \log \text{ bevel of } AB & = 9.65758 \\
\multicolumn{3}{l}{\text{bevel of } AB = 5\tfrac{7}{16} \text{ in.}} \\
\text{sq. } BC & = \text{sq. } 7 \text{ ft. } 6 \text{ in.} & = 56.2500 \\
\text{sq. } AC & = \text{sq. } 16 \text{ ft. } 6 \text{ in.} & = \underline{272.2500} \\
 & \qquad \text{sq. } AB & = 328.5000 \\
 & \qquad AB & = 18 \text{ feet } 1\tfrac{1}{2} \text{ inches}
\end{array}
$$

The results of the computations may be checked by verifying whether $\sec^2 A = 1 + \tan^2 A$ in the following manner: When the length of AB is found, record its logarithm. Subtract the logarithm of AC from the logarithm of AB, thereby obtaining $\log \sec A$. Look for that logarithm in the Parallel Tables and



Truss T1L
Truss T1R
Truss T2
32'-0" Clear Span
(a)
Stresses in 1,000 lb.
− Denotes Compression
+ Denotes Tension
4" Reinf. Conc. Slab
7'-6"
-39.8
+36.3
-31.9
-8.0
-6.6
+13.5
+21.8
2-L $2\frac{1}{2}$"X$2\frac{1}{2}$"X$\frac{5}{16}$"
L-$2\frac{1}{2}$"X2"X$\frac{1}{4}$"
Sliding
Fixed
32'-0" Clear Span
33'-0" C. to C. Bearings
(b)

FIG. 76

see whether the square corresponding to it equals the square of the bevel increased by 1. The operations are as follows:

$$\text{sq. } 5\tfrac{7}{16} \text{ in.} = 0.2053 \qquad \log AB = 1.25828$$
$$1 + \tan^2 A = 1.2053 \qquad \log AC = \underline{1.21748}$$
$$\log \sec A = 0.04080$$

The square corresponding to the logarithm 0.04080 is 1.2077, which, of the various values given in the table, is nearest to

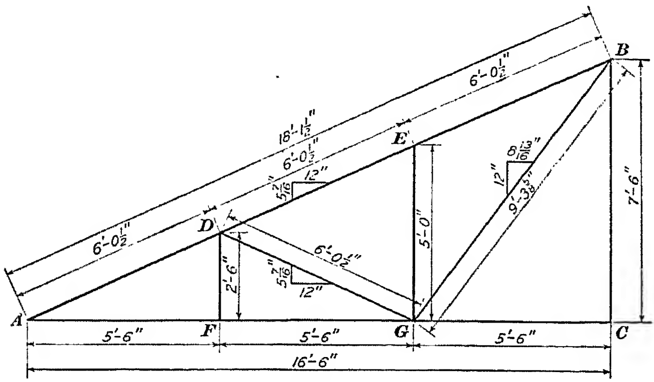


FIG. 77

1.2053, and therefore indicates that the computations were correctly performed. A more compact manner of recording the computations is the following tabular form:

	Number	Log	Square
BC	7 ft. 6 in.	0.87506	56.2500
AC	16 ft. 6 in.	1.21748	272.2500
AB	18 ft. $1\frac{1}{2}$ in.	1.25828	328.5000
$\tan A$ = bevel of AB.	$5\frac{7}{16}$ in.	9.65758	0.2053
$\sec A$	. . . .	0.04080	1.2053

114. Since the top chord is divided into three equal panels, the length of each panel is 18 ft. $1\frac{1}{2}$ in. $\div 3 = 6$ ft. $0\frac{1}{2}$ in. Likewise, since the bottom is divided into three equal parts, the length of each part is 16 ft. 6 in. $\div 3 = 5$ ft. 6 in.

The triangle ADF is evidently similar to the triangle ABC and their corresponding sides are proportional. Therefor since AF is one-third of AC, DF is one-third of BC, or 2 ft. in. For a like reason, EG is two-thirds of BC, or 5 ft. 0 in.

Triangle DFG is equal to triangle AFD, because the le DF is common to the two right triangles and the leg AF equal to the leg FG. Hence, the length of DG is equal to th length of AD, or 6 feet $0\frac{1}{2}$ inch, and the bevel of DG is equa to the bevel of AD, or $5\frac{7}{16}$ inches in 12 inches.

In the right triangle BCG, the leg BC is 7 ft. 6 in. and the le GC is 5 feet 6 inches. The bevel and length of BG are there fore computed as follows:

	Number	Log	Square
GC	5 ft. 6 in.	0.74036	30.2500
BC	7 ft. 6 in.	0.87506	56.2500
BG	9 ft. $3\frac{5}{8}$ in.		86.5000
bevel of BG	$8\frac{13}{16}$ in.	9.86530	

115. Design of Riveted Joints.—After the lengths an bevels of the members have been computed, it is necessary t determine the number of rivets required for the connection o each member to the gusset plate to transmit safely the stres in the member. In Fig. 76 (*b*) are given the stresses in thou sands of pounds in the various members of the truss. Tensil stresses are indicated by a plus sign, and compressive stresse by a minus sign. If all rivets in the truss are assumed to b of $\frac{3}{4}$-inch diameter, and the unit shearing stress for shop rivet is assumed to be 12,000 pounds per square inch, the single shearing value of each rivet is $.7854\times(\frac{3}{4})^2\times12{,}000=5{,}30$ pounds and its double-shearing value is 10,600 pounds. Also if the unit bearing stress is assumed to be 24,000 pounds pe square inch, the unit bearing value of each rivet on a $\frac{3}{8}$-inch gusset plate is $\frac{3}{8}\times\frac{3}{4}\times24{,}000=6{,}750$ pounds. The numbers o rivets required at the various joints are therefore as follows:

Joint A.—The stress in AD is 39,800 pounds compression and the number of rivets required to transmit that stress i

$\frac{39,800}{6,750}=5.9$, say 6. The rivets connecting the member AF to the gusset plate at A must resist the stress in AF, which is 36,300 pounds tension, and the vertical reaction of the truss. The resultant of the horizontal tension and the vertical reaction at A is exactly equal to the stress in AD; hence, the number of rivets in AD and AF should be the same.

Joint D.—The member DF carries no stress but is used merely to support the bottom chord; hence, the minimum number of rivets, two, will be used. The stress in member DG is 8,000 pounds compression, and $\frac{8,000}{6,750}=1.2$, say two, rivets will be required. The stress in member AD is 39,800 pounds compression and in member DE 31,900 pounds compression; hence, the required number of rivets in the top chord at joint D is $\frac{39,800-31,900}{6,750}=\frac{7,900}{6,750}=1.2$, say two, but for practical considerations four will be used as shown on the plate.

Joint F.—As previously determined, two rivets will be used in member DF. Since the stress in the bottom chord is the same on both sides of the joint, theoretically no rivets are required in it at the joint, but to hold the gusset plate in place two rivets will be employed.

Joint E.—The stress in EG is 6,600 pounds compression and two rivets will be used. Also, in the top chord, since the stress is the same on both sides of the joint, two rivets will be used to hold the gusset plate in place.

Joint G.—As previously determined, two rivets will be used in each of members DG and EG. The stress in member GB is 13,500 pounds tension, and $\frac{13,500}{6,750}=2$ rivets will be used. The stress in member FG is 36,300 pounds tension, and in member GC, 21,800 pounds tension; hence, the number of rivets required in the bottom chord at joint G is $\frac{36,300-21,800}{6,750}$ $=2.15$, say three, but for practical consideration four will be used.

Joint B.—The stress in BE is 31,900 pounds compression, and $\frac{31,900}{6,750}=4.73$, or five rivets are required. As previously determined two rivets will be used in member GB. Since member BC carries no stress it will be connected with two rivets. The members in the right half of the truss carry the same stresses as their corresponding members in the left half of the truss and they will have the same number of rivets.

Joint C.—The conditions at joint C being similar to those at joint F, the same detail will be employed.

116. Sole Plate.—As determined by the conditions of the design, the masonry and sole plates at the ends of the truss will each be a $12'' \times \frac{1}{2}'' \times 11''$ plate, the length of bearing for the truss being 12 inches. Only the sole plate need be shown on the detail drawing, because it is riveted to the truss by means of four rivets countersunk on the bottom, while the masonry plate is shipped loose. The $\frac{15}{16}$-inch holes in the sole plate for the $\frac{7}{8}$-inch-diameter anchor bolts will be slotted 2 inches at the left end of the truss so as to enable the sole plate to slide over the masonry plate because the truss will contract in cold weather and expand in warm weather.

117. Layouts.—After the lengths and bevels of the members and the numbers of rivets in the joints have been determined, the elevation of the truss may be drawn. However, in order to determine the best shape and size of the gusset plates, and the distances from the working points to the ends of the members, preliminary drawings of the joints are carefully drawn to a large scale, such as $1\frac{1}{2}$ inches = 1 foot or 3 inches = 1 foot, and the desired dimensions are scaled on these drawings. These preliminary drawings are known as *layouts*. They are used only when the axes of the members at the joint intersect at angles other than right angles, because when the angle of intersection is a right angle the various dimensions may be easily determined without a layout.

As an illustration of the manner in which layouts are drawn, directions for drawing the layout of joint A at the heel of the truss will now be given. The layout is shown in Fig. 78.

First draw a horizontal line to represent the working line of the bottom chord and choose some point p along that line as the working point for the joint. From the point p draw the working line of the top chord at a bevel of $5\frac{7}{16}$ inches in 12 inches, as follows. Lay off from p along the working line of the bottom chord 12 inches to one-half scale, or the distance $p\,t$. At t erect a perpendicular to the working line of the bottom chord and lay off from t along the perpendicular $5\frac{7}{16}$ inches to one-half scale, or the distance $t\,u$. Join the points p and u, establishing the working line of the top chord. In this layout the bevel only is laid out to one-half scale.

To the left of point p lay off 6 inches to the end of the bottom chord, using a scale of 3 inches = 1 foot. Lay off below

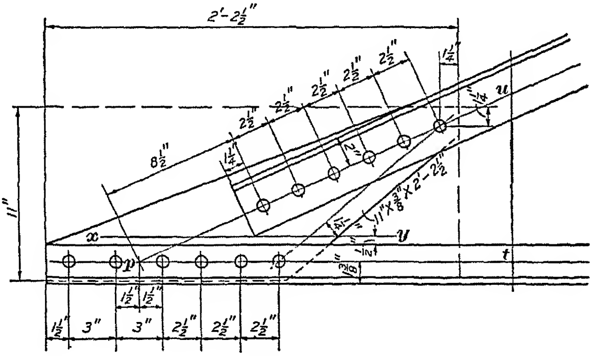


Fig. 78

the working line of the bottom chord $1\frac{3}{8}$ inches to the back of the bottom-chord angles and above that line $1\frac{1}{8}$ inches to the edge of the angles and draw the lines as shown. Draw the clearance line, $x\,y$, $\frac{1}{2}$ inch above the edge of the angles. Now lay off 2 inches above the working line of the top chord to the back of the top-chord angles and $1\frac{1}{2}$ inches below that line to the edge of the angles. Prolong the edge until it intersects the clearance line $x\,y$, and draw the end of the angles from that point of intersection. Now locate the rivets in the bottom chord; first, place one rivet on each side of the working point and $1\frac{1}{2}$ inches from it, so as to clear the rivets in the outstanding legs of the angles, which rivets are to be 3 inches on each side

of the line through the working point; then place the extreme rivet to the left, $1\frac{1}{2}$ inches from the end of the chord, and finally the remaining rivets $2\frac{1}{2}$ inches center to center. Locate the rivets in the top chord so that the first rivet is $1\frac{1}{4}$ inches from the end of the angles, and the remaining rivets are $2\frac{1}{2}$ inches center to center. Dot the bottom edge of the gusset plate $1\frac{1}{4}$ inches below the working line for the bottom chord. Join the center lines of the extreme right-hand rivets in the top and bottom chords and draw the edge of the plate $1\frac{1}{4}$ inches below that line. Dot the extreme top and right-hand edge of the plate $1\frac{1}{4}$ inches from the top rivet, and complete the outline of the plate. By scaling, it is found that the distance from the working point to the center of the first rivet in the top chord is $8\frac{1}{2}$ inches, and that the gusset may be cut from a rectangular plate 11 inches wide by 2 feet $2\frac{1}{2}$ inches long.

The layouts for the other joints are made in similar manner, and the information thus obtained is used in detailing the truss.

118. Bracing.—Since the roof covering in this building is a 4-inch reinforced-concrete slab supported on the purlins throughout the building and on the brick end walls at the ends of the building, it is not necessary to provide bracing rods in the top chord. No ridge strut will be used, but the purlins at the peak of the truss are relied on to fulfil the function of the ridge strut and therefore are connected by means of longer clip angles and more bolts than are the other purlins.

The bottom chord is braced as shown in Fig. 76 (*a*). In the bays next to the end bays cross-bracing made of single $3\frac{1}{2}''\times2\frac{1}{2}''\times\frac{5}{16}''$ angles and struts consisting of two $4''\times3''\times\frac{5}{16}''$ angles riveted back to back are used, while in the other bays no cross-bracing is used, but ties of single $4''\times3''\times\frac{5}{16}''$ angles are located at the center of the truss. The details of the connections of the various bracing members to the bottom chord of each truss are shown in Fig. 79: in (*a*) is the connection of one of the cross-braces to the chord near the end of the truss, in (*b*) is the connection of the cross-braces

and struts to the bottom chord at the center of the span, and in (*c*) is the connection of the ties to the bottom chord of a truss in unbraced bays. On account of the difference in provision for the connections of the bracing members, three kinds of trusses are used in the building: two trusses $T1^R$, provided with holes as shown in (*a*) and (*b*) in Fig. 79; two trusses $T1^L$, which are exactly opposite to $T1^R$; and two trusses

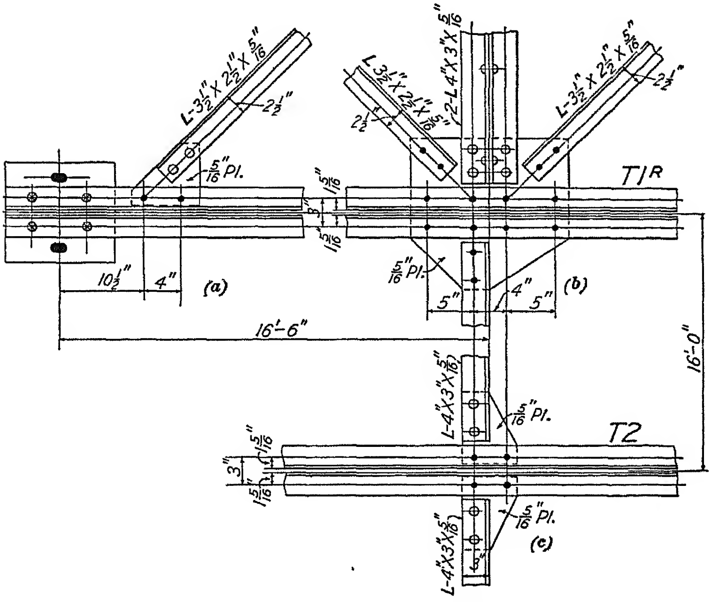


FIG. 79

T2, which are provided with holes only at the center of the span as shown in (*c*). However, all three kinds of trusses are detailed on one sketch.

119. Key Plan.—In the upper left-hand corner of Plate 4 is shown a key plan or marking diagram of the roof, in which the arrangement of the various trusses and the bracing members are shown. Such plans should give the spacing of the trusses and their identification marks. The function of the key plan is to aid the draftsman in making correct details of the

truss, the checker in verifying the correctness of the draw and the shop inspector in ascertaining whether the pr provisions for field connections have been made in the tru constructed in the shop.

In detailing trusses for simple construction, as in this c it is not essential to draw the key plan, and it is here gi mainly to explain the meaning and function of such pl In more complex construction, however, such plans serv very useful purpose. They are usually drawn to a small sc the one here used being 1 inch = 30 feet.

120. Directions for Drawing Plate 4.—First lay out working lines of the truss to agree with Fig. 77 in the t locating point *A* $4\frac{3}{4}$ inches, full size, above the bottom bor line and $2\frac{1}{2}$ inches from the left-hand border line, and usir scale of $\frac{3}{4}$ inch = 1 foot for laying out the dimensions of truss. Dimension the various working lines, drawing lines for the over-all dimensions of the various members about the same relative positions as shown on the sam sheet. Detail joint *A* at the heel of the truss, following dimensions shown on the sample sheet, and draw the top bottom chord angles in elevation. Detail joints *D*, *F*, *G*, *B*, and *C* in consecutive order and draw the various memb dimensioning each member immediately after it is drawn.

After the elevation of the truss has been completed, draw center line for the top view of the top chord at a distance $1\frac{7}{8}$ inches, full size, measured perpendicularly, above backs of the angles of the top chord, and complete the vi as shown on the sample sheet. Next, draw the center l for the bottom-sectional view $2\frac{5}{8}$ inches, full size, above bottom border line, and complete the view as shown. Fina draw the diagram entitled *Plan of Roof* to a scale of 1 in = 30 feet in about the same relative position as shown on sample sheet. Letter all notes and complete the plate.

TABLES OF STRUCTURAL STEEL DETAILS

121. Tables I and II give the standard dimensions and weights for structural-steel angles. Tables III and IV show the dimensions of channels and **I** beams, and the sizes of their

TABLE I

DIMENSIONS FOR EQUAL ANGLES

Size	Thickness	Weight per Foot	Size	Thickness	Weight per Foot	Size	Thickness	Weight per Foot	Size	Thickness	Weight per Foot
Inches	In	Lb.	Inches	In.	Lb.	Inches	In.	Lb.	Inches	In.	Lb.
	1 1/8	56.9		7/8	27.2					1/4	3.19
	1 1/16	54.0		13/16	25.4		1/2	11.1	2×2	3/16	2.44
	1	51.0		3/4	23.6		7/16	9.8		1/8	1.65
	15/16	48.1		11/16	21.8	3 1/2×3 1/2	3/8	8.5			
	7/8	45.0	5×5	5/8	20.0		5/16	7.2		7/16	4.6
8×8	13/16	42.0		9/16	18.1		1/4	5.8		3/8	3.99
	3/4	38.9		1/2	16.2					5/16	3.39
	11/16	35.8		7/16	14.3		5/8	11.5	1 3/4×1 3/4	1/4	2.77
	5/8	32.7		3/8	12.3		9/16	10.4		3/16	2.12
	9/16	29.6					1/2	9.4		1/8	1.44
	1/2	26.4		13/16	19.9	3×3	7/16	8.3			
				3/4	18.5		3/8	7.2		3/8	3.35
	1	37.4		11/16	17.1		5/16	6.1		5/16	2.86
	15/16	35.3		5/8	15.7		1/4	4.9	1 1/2×1 1/2	1/4	2.34
	7/8	33.1	4×4	9/16	14.3					3/16	1.80
	13/16	31.0		1/2	12.8		1/2	7.7		1/8	1.23
	3/4	28.7		7/16	11.3		7/16	6.8			
6×6	11/16	26.5		3/8	9.8		3/8	5.9			
	5/8	24.2		5/16	8.2	2 1/2×2 1/2	5/16	5.0		5/16	2.33
	9/16	21.9		1/4	6.6		1/4	4.1	1 1/4×1 1/4	1/4	1.92
	1/2	19.6					3/16	3.07		3/16	1.48
	7/16	17.2		13/16	17.1		1/8	2.08		1/8	1.01
	3/8	14.9		3/4	16.0						
			3 1/2×3 1/2	11/16	14.8		7/16	5.3		1/4	1.49
5×5	1	30.6		5/8	13.6	2×2	3/8	4.7	1×1	3/16	1.16
	15/16	28.9		9/16	12.4		5/16	3.92		1/8	0.80

bearing plates. Table V gives rivet pitches and edge distances. Table VI shows standard rivet gauges for angles. Table VII shows the clearance required for machine-driven rivets. Table VIII shows the dimensions for **H** beams.

TABLE II

DIMENSIONS FOR UNEQUAL ANGLES

Size	Thickness	Weight per foot
Inches	In.	Lb.
8×6	1	44.2
	15/16	41.7
	7/8	39.1
	13/16	36.5
	3/4	33.8
	11/16	31.2
	5/8	28.5
	9/16	25.7
	1/2	23.0
	7/16	20.2
8×3½	1	35.7
	15/16	33.7
	7/8	31.7
	13/16	29.6
	3/4	27.5
	11/16	25.3
	5/8	23.2
	9/16	21.0
	1/2	18.7
	7/16	16.5
7×3½	1	32.3
	15/16	30.5
	7/8	28.7
	13/16	26.8
	3/4	24.9
	11/16	23.0
	5/8	21.0
	9/16	19.1
	1/2	17.0
	7/16	15.0
	3/8	13.0
6×4	1	30.6
	15/16	28.9
	7/8	27.2
	13/16	25.4
	3/4	23.6
	11/16	21.8
	5/8	20.0
	9/16	18.1
	1/2	16.2
	7/16	14.3
	3/8	12.3

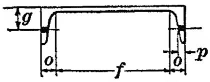
Size	Thickness	Weight per Foot
Inches	In.	Lb.
6×3½	1	28.9
	15/16	27.3
	7/8	25.7
	13/16	24.0
	3/4	22.4
	11/16	20.6
	5/8	18.9
	9/16	17.1
	1/2	15.3
	7/16	13.5
	3/8	11.7
	5/16	9.8
5×4	7/8	24.2
	13/16	22.7
	3/4	21.1
	11/16	19.5
	5/8	17.8
	9/16	16.2
	1/2	14.5
	7/16	12.8
	3/8	11.0
5×3½	7/8	22.7
	13/16	21.3
	3/4	19.8
	11/16	18.3
	5/8	16.8
	9/16	15.2
	1/2	13.6
	7/16	12.0
	3/8	10.4
	5/16	8.7
5×3	13/16	19.9
	3/4	18.5
	11/16	17.1
	5/8	15.7
	9/16	14.3
	1/2	12.8
	7/16	11.3
	3/8	9.8
	5/16	8.2
4½×3	13/16	18.5
	3/4	17.3
	11/16	16.0

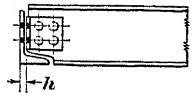
Size	Thickness	Weight per Foot
Inches	In.	Lb.
4½×3	5/8	14.7
	9/16	13.3
	1/2	11.9
	7/16	10.6
	3/8	9.1
	5/16	7.7
4×3½	13/16	18.5
	3/4	17.3
	11/16	16.0
	5/8	14.7
	9/16	13.3
	1/2	11.9
	7/16	10.6
	3/8	9.1
	5/16	7.7
4×3	13/16	17.1
	3/4	16.0
	11/16	14.8
	5/8	13.6
	9/16	12.4
	1/2	11.1
	7/16	9.8
	3/8	8.5
	5/16	7.2
	1/4	5.8
3½×3	13/16	15.8
	3/4	14.7
	11/16	13.6
	5/8	12.5
	9/16	11.4
	1/2	10.2
	7/16	9.1
	3/8	7.9
	5/16	6.6
	1/4	5.4
3½×2½	11/16	12.5
	5/8	11.5
	9/16	10.4
	1/2	9.4
	7/16	8.3
	3/8	7.2
	5/16	6.1
	1/4	4.9

Size	Thickness	Weight per Foot
Inches	In.	Lb.
3×2½	9/16	9.5
	1/2	8.5
	7/16	7.6
	3/8	6.6
	5/16	5.6
	1/4	4.5
3×2	1/2	7.7
	7/16	6.8
	3/8	5.9
	5/16	5.0
	1/4	4.1
2½×2	1/2	6.8
	7/16	6.1
	3/8	5.3
	5/16	4.5
	1/4	3.62
	3/16	2.75
	1/8	1.86
2½×1½	5/16	3.92
	1/4	3.19
	3/16	2.44
2¼×1½	1/2	5.6
	7/16	5.0
	3/8	4.4
	5/16	3.66
	1/4	2.98
	3/16	2.28
2×1½	3/8	3.99
	5/16	3.39
	1/4	2.77
	3/16	2.12
	1/8	1.44
2×1¼	1/4	2.55
	3/16	1.96
1¾×1¼	1/4	2.34
	3/16	1.80
	1/8	1.23
1½×1¼	5/16	2.59
	1/4	2.13
	3/16	1.64

TABLE III

GAUGES AND DIMENSIONS FOR CHANNELS

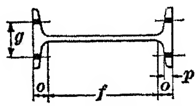


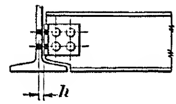


Depth of Channel	Weight per Foot	Flange Width	Web Thickness	½ Web Thickness	Gauge g	Grip p	Distance f	Distance o	Distance h	Max. Rivet In Flange	Size of Bearing Plate
In.	Lb.	In.	In.	In.	In.	In.	In.	In.	In.	In.	
15	55.0	3 7/8	13/16	7/16	2 1/2	11/16	12 1/4	1 3/8	7/8	7/8	12″×1″×1′4″
	50.0	3 3/4	11/16	3/8	2 1/2	11/16	12 1/4	1 3/8	13/16		
	45.0	3 5/8	5/8	5/16	2	5/8	12 1/4	1 3/8	11/16		
	40.0	3 1/2	1/2	1/4	2	5/8	12 1/4	1 3/8	9/16		
	35.0	3 7/16	7/16	3/16	2	5/8	12 1/4	1 3/8	1/2		
	33.9	3 3/8	3/8	3/16	2	5/8	12 1/4	1 3/8	1/2		
13	50.0	4 3/8	13/16	3/8	3	9/16	10 1/2	1 1/4	7/8	7/8	12″×1″×1′0″
	45.0	4 1/4	11/16	5/16	2 3/4	9/16	10 1/2	1 1/4	3/4		
	40.0	4 1/8	9/16	1/4	2 3/4	9/16	10 1/2	1 1/4	5/8		
	37.0	4 1/8	1/2	1/4	2 1/2	9/16	10 1/2	1 1/4	9/16		
	35.0	4 1/8	7/16	1/4	2 1/2	9/16	10 1/2	1 1/4	1/2		
	31.8	4	3/8	3/16	2 1/2	9/16	10 1/2	1 1/4	7/16		
12	40.0	3 3/8	3/4	3/8	2	5/8	10	1	13/16	7/8	12″×3/4″×1′0″
	35.0	3 1/4	5/8	5/16	2	5/8	10	1	11/16		
	30.0	3 1/8	1/2	1/4	1 3/4	1/2	10	1	9/16		
	25.0	3	3/8	3/16	1 3/4	1/2	10	1	7/16		
	20.7	3	1/4	1/8	1 3/4	1/2	10	1	3/8		
10	35.0	3 1/8	13/16	7/16	1 3/4	1/2	8 1/4	7/8	7/8	3/4	8″×3/4″×1′0″
	30.0	3	11/16	5/16	1 3/4	1/2	8 1/4	7/8	3/4		
	25.0	2 7/8	1/2	1/4	1 3/4	1/2	8 1/4	7/8	9/16		
	20.0	2 3/4	3/8	3/16	1 1/2	7/16	8 1/4	7/8	7/16		
	15.3	2 5/8	1/4	1/8	1 1/2	7/16	8 1/4	7/8	5/16		
9	25.0	2 7/8	5/8	5/16	1 1/2	1/2	7 1/4	7/8	11/16	3/4	8″×5/8″×1′0″
	20.0	2 5/8	7/16	1/4	1 1/2	1/2	7 1/4	7/8	1/2		
	15.0	2 1/2	5/16	1/8	1 3/8	7/16	7 1/4	7/8	3/8		
	13.4	2 3/8	1/4	1/8	1 3/8	7/16	7 1/4	7/8	5/16		
8	21.25	2 5/8	9/16	5/16	1 1/2	7/16	6 1/4	7/8	11/16	3/4	8″×5/8″×8″
	18.75	2 1/2	1/2	1/4	1 1/2	7/16	6 1/4	7/8	9/16		
	16.25	2 3/8	3/8	3/16	1 1/2	7/16	6 1/4	7/8	1/2		
	13.75	2 3/8	5/16	1/8	1 3/8	3/8	6 1/4	7/8	3/8		
	11.5	2 1/4	1/4	1/8	1 3/8	3/8	6 1/4	7/8	5/16		
7	19.75	2 1/2	5/8	5/16	1 1/2	7/16	5 1/2	3/4	11/16	5/8	
	17.25	2 3/8	1/2	1/4	1 1/2	7/16	5 1/2	3/4	9/16		
	14.75	2 1/4	7/16	3/16	1 1/4	7/16	5 1/2	3/4	1/2		
	12.25	2 1/4	5/16	3/16	1 1/4	3/8	5 1/2	3/4	3/8		
	9.8	2 1/8	3/16	1/8	1 1/4	3/8	5 1/2	3/4	5/16		
6	15.5	2 1/4	9/16	1/4	1 3/8	3/8	4 1/2	3/4	5/8	5/8	6″×1/2″×6″
	13.0	2 1/8	7/16	1/4	1 3/8	3/8	4 1/2	3/4	1/2		
	10.5	2	5/16	3/16	1 1/8	3/8	4 1/2	3/4	3/8		
	8.2	1 7/8	3/16	1/8	1 1/8	5/16	4 1/2	3/4	1/4		
5	11.5	2	1/2	1/4	1 1/8	5/16	3 3/4	5/8	9/16	1/2	
	9.0	1 7/8	5/16	3/16	1 1/8	5/16	3 3/4	5/8	3/8		
	6.7	1 3/4	3/16	1/8	1 1/8	5/16	3 3/4	5/8	1/4		
4	7.25	1 3/4	5/16	3/16	1	5/16	2 3/4	5/8	3/8	1/2	4″×3/8″×4″
	6.25	1 5/8	1/4	1/8	1	5/16	2 3/4	5/8	5/16		
	5.4	1 5/8	3/16	1/16	1	5/16	2 3/4	5/8	1/4		
3	6.0	1 5/8	3/8	3/16	7/8	1/4	1 3/4	5/8	7/16	1/2	
	5.0	1 1/2	1/4	1/8	7/8	1/4	1 3/4	5/8	5/16		
	4.1	1 3/8	3/16	1/16	7/8	1/4	1 3/4	5/8	1/4		

TABLE IV

GAUGES AND DIMENSIONS FOR I BEAMS





Depth of Beam	Weight per Foot	Flange Width	Web Thickness	½ Web Thickness	Gauge g	Grip p	Distance f	Distance o	Distance h	Max. Rivet in Flange	Size of Bearing Plate
In.	Lb.	In.	In.	In.	In.	In.	In.	In.	In.	In.	
27*	90.0	9	1/2	1/4	5	3/4	22 1/2	2 1/4	5/16	7/8	16″×1″×1′4″
24	120.0	8	13/16	3/8	5	1 1/8	20 1/4	1 7/8	1/2	7/8	
	115.0	8	3/4	3/8	5	1 1/8	20 1/4	1 7/8	7/16		
	110.0	7 7/8	11/16	5/16	5	1 1/8	20 1/4	1 7/8	7/16		
	105.9	7 7/8	5/8	5/16	5	1 1/8	20 1/4	1 7/8	3/8		
24	100.0	7 1/4	3/4	3/8	4	7/8	20 3/4	1 5/8	7/16	7/8	
	95.0	7 1/8	11/16	5/16	4	7/8	20 3/4	1 5/8	7/16		
	90.0	7 1/8	5/8	5/16	4	7/8	20 3/4	1 5/8	3/8		
	85.0	7 1/8	9/16	5/16	4	7/8	20 3/4	1 5/8	3/8		
	79.9	7	1/2	1/4	4	7/8	20 3/4	1 5/8	5/16		
24*	74.2	9	1/2	1/4	4	5/8	20	2	5/16	7/8	
21*	60.4	8 1/4	7/16	3/16	4	9/16	17 1/2	1 3/4	1/4	7/8	
20	100.0	7 1/4	7/8	7/16	4	1	16 1/2	1 3/4	1/2	7/8	
	95.0	7 1/4	13/16	3/8	4	1	16 1/2	1 3/4	1/2		
	90.0	7 1/8	3/4	3/8	4	1	16 1/2	1 3/4	7/16		
	85.0	7	5/8	5/16	4	1	16 1/2	1 3/4	3/8		
	81.4	7	5/8	5/16	4	1	16 1/2	1 3/4	3/8		
20	75.0	6 3/8	5/8	5/16	4	3/4	17	1 1/2	3/8	7/8	
	70.0	6 3/8	9/16	5/16	4	3/4	17	1 1/2	3/8		
	65.4	6 1/4	1/2	1/4	4	3/4	17	1 1/2	5/16		
18	90.0	7 1/4	13/16	3/8	4	1	14 1/2	1 3/4	1/2	7/8	
	85.0	7 1/8	11/16	3/8	4	1	14 1/2	1 3/4	7/16		
	80.0	7 1/8	5/8	5/16	4	1	14 1/2	1 3/4	3/8		
	75.6	7	9/16	1/4	4	1	14 1/2	1 3/4	3/8		
18	70.0	6 1/4	11/16	3/8	3 3/4	3/4	15 1/4	1 3/8	7/16	7/8	
	65.0	6 1/8	5/8	5/16	3 3/4	3/4	15 1/4	1 3/8	3/8		
	60.0	6 1/8	9/16	1/4	3 3/4	3/4	15 1/4	1 3/8	3/8		
	54.7	6	7/16	1/4	3 3/4	3/4	15 1/4	1 3/8	5/16		
18*	48.2	7 1/2	3/8	3/16	3 3/4	1/2	14 3/4	1 5/8	1/4	7/8	
15	75.0	6 1/4	7/8	7/16	3 1/2	7/8	11 3/4	1 5/8	1/2	3/4	
	70.0	6 1/8	3/4	3/8	3 1/2	7/8	11 3/4	1 5/8	7/16		
	65.0	6 1/8	11/16	5/16	3 1/2	7/8	11 3/4	1 5/8	7/16		
	60.8	6	9/16	5/16	3 1/2	7/8	11 3/4	1 5/8	3/8		
15	55.0	5 3/4	5/8	5/16	3 1/2	5/8	12 1/2	1 1/4	3/8	3/4	12″×1″×1′4″
	50.0	5 5/8	9/16	1/4	3 1/2	5/8	12 1/2	1 1/4	3/8		
	45.0	5 1/2	7/16	1/4	3 1/2	5/8	12 1/2	1 1/4	5/16		
	42.9	5 1/2	7/16	3/16	3 1/2	5/8	12 1/2	1 1/4	1/4		
15*	37.3	6 3/4	5/16	3/16	3 1/2	7/16	12 1/4	1 3/8	1/4	3/4	

*Special beams.

TABLE IV—(*Continued*)

GAUGES AND DIMENSIONS FOR I BEAMS

Depth of Beam	Weight per Foot	Flange Width	Web Thickness	½ Web Thickness	Gauge g	Grip p	Distance f	Distance o	Distance h	Max. Rivet in Flange	Size of Bearing Plate
In.	Lb.	In.	In.	In.	In.	In.	In.	In.	In.	In.	
12	55.0	5 5/8	1 3/16	3/8	3 1/2	3/4	9 1/4	1 3/8	1/2	3/4	12″×3/4″×1′0″
	50.0	5 1/2	1 1/16	5/16	3 1/2	3/4	9 1/4	1 3/8	7/16		
	45.0	5 3/8	9/16	5/16	3	3/4	9 1/4	1 3/8	3/8		
	40.8	5 1/4	7/16	1/4	3	3/4	9 1/4	1 3/8	5/16		
12	35.0	5 1/8	7/16	3/16	3	9/16	9 3/4	1 1/8	5/16	3/4	
	31.8	5	3/8	3/16	3	9/16	9 3/4	1 1/8	1/4		
12*	27.9	6	5/16	1/8	3	7/16	9 1/2	1 1/4	3/16	3/4	
10	40.0	5 1/8	3/4	3/8	2 3/4	1/2	8	1	7/16	3/4	8″×3/4″×1′0″
	35.0	5	5/8	5/16	2 3/4	1/2	8	1	3/8		
	30.0	4 3/4	7/16	1/4	2 3/4	1/2	8	1	5/16		
	25.4	4 5/8	5/16	1/8	2 3/4	1/2	8	1	1/4		
10*	22.4	5 1/2	1/4	1/8	2 3/4	3/8	7 3/4	1 1/8	3/16	3/4	
9	35.0	4 3/4	3/4	3/8	2 1/2	1/2	7	1	7/16	3/4	8″×5/8″×1′0″
	30.0	4 5/8	9/16	1/4	2 1/2	1/2	7	1	3/8		
	25.0	4 1/2	3/8	3/16	2 1/2	1/2	7	1	1/4		
	21.8	4 3/8	5/16	1/8	2 1/2	1/2	7	1	3/16		
8	25.5	4 1/4	9/16	1/4	2 1/4	1/2	6 1/4	7/8	5/16	3/4	8″×5/8″×8″
	23.0	4 1/8	7/16	1/4	2 1/4	7/16	6 1/4	7/8	5/16		
	20.5	4 1/8	3/8	3/16	2 1/4	7/16	6 1/4	7/8	1/4		
	18.4	4	1/4	1/8	2 1/4	7/16	6 1/4	7/8	3/16		
8*	17.5	5	1/4	1/8	2 1/4	3/8	6	1	3/16	3/4	
7	20.0	3 7/8	7/16	1/4	2 1/4	3/8	5 1/4	7/8	5/16	5/8	
	17.5	3 3/4	3/8	3/16	2 1/4	3/8	5 1/4	7/8	1/4		
	15.3	3 5/8	1/4	1/8	2 1/4	3/8	5 1/4	7/8	3/16		
6	17.25	3 5/8	7/16	1/4	2	3/8	4 1/2	3/4	5/16	5/8	6″×1/2″×6″
	14.75	3 1/2	3/8	3/16	2	3/8	4 1/2	3/4	1/4		
	12.5	3 3/8	1/4	1/8	2	3/8	4 1/2	3/4	3/16		
5	14.75	3 3/8	1/2	1/4	1 3/4	3/8	3 1/2	3/4	5/16	1/2	
	12.25	3 1/8	3/8	3/16	1 3/4	3/8	3 1/2	3/4	1/4		
	10.0	3	3/16	1/8	1 3/4	3/8	3 1/2	3/4	3/16		
4	10.5	2 7/8	3/8	3/16	1 1/2	5/16	2 3/4	5/8	1/4	1/2	4″×3/8″×4″
	9.5	2 3/4	5/16	3/16	1 1/2	5/16	2 3/4	5/8	1/4		
	8.5	2 3/4	1/4	1/8	1 1/2	5/16	2 3/4	5/8	3/16		
	7.7	2 5/8	3/16	1/8	1 1/2	5/16	2 3/4	5/8	3/16		
3	7.5	2 1/2	3/8	3/16	1 1/2	5/16	1 3/4	5/8	1/4	3/8	
	6.5	2 3/8	1/4	1/8	1 1/2	5/16	1 3/4	5/8	3/16		
	5.7	2 3/8	3/16	1/16	1 1/2	5/16	1 3/4	5/8	1/8		

*Special Beams.

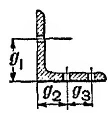
TABLE V

RIVET PITCH AND EDGE DISTANCE, IN INCHES

Diameter of Rivet, in Inches	3/8	1/2	5/8	3/4	7/8	1	1 1/8
Minimum pitch based on 3 diameters.	1 1/8	1 1/2	1 7/8	2 1/4	2 5/8	3	3 3/8
Usual minimum pitch....................	1 1/4	1 3/4	2	2 1/4	2 5/8	3	3 3/8
Usual maximum pitch....................	4	4	4 1/2	6	6	6	6
Minimum edge distance based on 2 diameters	3/4	1	1 1/4	1 1/2	1 3/4	2	2 1/4
Usual minimum edge distance..............	3/4	1	1 1/8	1 1/4	1 1/2	1 3/4	2
Extreme minimum edge distance..........	9/16	3/4	15/16	1 1/8	1 5/16	1 1/2	1 11/16

TABLE VI

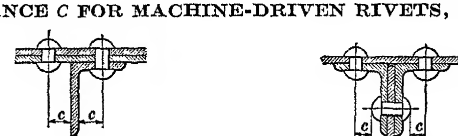
STANDARD GAUGES FOR ANGLES, IN INCHES



Leg	8	7	6	5	4 1/2	4	3 1/2	3	2 1/2	2	1 3/4	1 1/2	1 1/4	1	3/4
g_1	4 1/2	4	3 1/2	3	2 1/2	2 1/2	2	1 3/4	1 3/8	1 1/8	1	7/8	3/4	5/8	1/2
g_2	3	2 1/2	2 1/2	2	2										
g_3	3	3	2 1/4	1 3/4	1 1/4										
Maximum rivet	1 1/8	1	7/8	7/8	7/8	7/8	7/8	7/8	3/4	5/8	1/2	3/8	3/8	1/4	1/4

TABLE VII

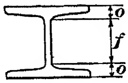
CLEARANCE *C* FOR MACHINE-DRIVEN RIVETS, IN INCHES



Diameter of Rivet, in Inches	1/2	5/8	3/4	7/8	1	1 1/8
Usual minimum clearance..................	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8
Extreme minimum clearance..............	3/4	7/8	1	1 1/8	1 1/4	1 3/8

TABLE VIII

DIMENSIONS FOR H BEAMS



Depth of Beam Inches	Weight per Foot Pounds	Flange Width Inches	Web Thickness Inch	Distance	
				f Inches	o Inch
8	34.3	8	3/8	6 1/4	7/8
6	24.1	6	5/16	4 1/4	7/8
5	18.9	5	5/16	3 3/8	13/16
4	13.8	4	5/16	2 1/2	3/4

ELEMENTS OF CONCRETE DRAWING

CONCRETE CONSTRUCTION

GENERAL EXPLANATIONS

INTRODUCTION AND DEFINITIONS

1. Introduction.—In this Section are treated the elements of concrete drawing. The conventional methods generally employed in making concrete drawings are here explained, and commonly used ways of detailing members of reinforced-concrete structures are introduced. However, before the subject can be taken up, it is necessary to discuss briefly certain fundamental principles concerning concrete and reinforced concrete, to illustrate the principal types of steel reinforcement that are in use, and to present typical construction of the members that make up reinforced-concrete buildings. This preliminary explanation is given in Arts. 2 to 42.

2. Cementing Materials.—A material which can be made plastic and that will then gradually harden to form an artificial stone is called a cementing material. The principal cementing materials used in building construction are Portland cement, natural cements, plaster cements, and limes; all can be made plastic by adding water.

3. Mortar.—A mixture of sand and a cementing material in proper proportions and in a plastic state is known as mortar.

In hardening, the cementing material binds together the particles of sand and forms a solid mass.

Mortar adheres to the surfaces of bodies against which it is placed, and these bodies in turn are bonded by the mortar. Thus, bricks or stones are bound together in a wall by laying mortar between them.

4. Concrete.—A mixture of pieces of broken stone, gravel, crushed slag, or cinders with a mortar of cement, sand, and water is called concrete. When freshly mixed, concrete is a plastic semifluid mass which can be poured into forms or molds and will take the shape of the mold. In about a half hour the mass begins to stiffen, in about a half day to a day it becomes hard, and in about a month it is as hard as most natural stones.

Concrete slabs, beams, girders, columns, and walls are made by pouring freshly mixed concrete into properly shaped molds and allowing the concrete to harden. After the concrete has hardened sufficiently the molds are removed. Concrete is thus used in all types of construction.

The material which is bound together by the cement in concrete is called *aggregate*. The part of the aggregate that is less than $\frac{1}{4}$ inch in size is generally called the *fine aggregate;* it usually includes only the sand. The part of the aggregate that is greater than $\frac{1}{4}$ inch in size is called the *coarse aggregate*. The maximum size of coarse aggregate in ordinary concrete is 3 inches.

5. Reinforced Concrete.—Reinforced concrete is concrete in which is embedded steel in the form of rods, bars, or netting for the purpose of aiding the concrete in carrying loads. The metal used with the concrete is called *reinforcement*. The reinforcement is usually so proportioned and distributed within the concrete that the concrete and the steel act together as one unit in carrying the loads.

PROPORTIONS OF CEMENT MORTAR AND CONCRETE

6. **Proportions of Cement Mortar.**—In mixing cement mortar, sufficient cement paste should be used to coat completely each grain of sand and to fill all spaces, or *voids*, between the grains. A strong and dense mortar can be obtained by mixing 1 part of cement with 2 parts of sand, as 1 cubic foot of cement with 2 cubic feet of sand; such a mixture is written 1:2 mortar, and is read *one-two mortar*. Cement mortars are made in proportions varying from 1:1 to 1:6. The mortars that contain a large proportion of cement are called *rich*, while those which contain a small proportion of cement are called *lean*. The richer mixtures are the stronger mixtures and are employed when great strength is required, while the leaner mixtures are the weaker mixtures and are employed when strength is not important.

7. **Proportions of Concrete.**—In forming concrete, the most satisfactory results are obtained when sufficient cement is employed to coat each grain of sand with cement paste, and sufficient mortar to coat each piece of the coarse aggregate in the concrete and to fill all the voids between the pieces. The proper proportions in which the ingredients should be mixed, in order to produce a concrete of desired strength and workability, are best determined by tests in the field. The percentage of voids in different coarse and fine aggregates varies considerably, depending upon the relative proportions of the particles of different size in the materials. Generally, the voids in a volume of broken stone or gravel occupy about 45 per cent. of the mass. Therefore, to fill these voids, a quantity of sand equal to about one-half the volume of the stone or gravel is required. When the proportions of the ingredients in concrete are selected arbitrarily, without preliminary tests, it is customary to use twice as much stone or gravel as sand. The strength of the concrete mixture is increased or decreased by increasing or decreasing the ratio of the cement to sand.

For ordinary purposes, the concrete mixture consists of 1 part of cement, 2 parts of sand, and 4 parts of stone or gravel;

this mixture is referred to as a 1:2:4 concrete, and read *one-two-four concrete*. Richer mixtures, such as $1:1\frac{1}{2}:3$, are often used for columns and pavements, while leaner mixtures, such as $1:2\frac{1}{2}:5$ and 1:3:6 are used in certain types of foundations and other work where bulk rather than strength is the important factor. Concrete mixtures are also expressed as ratios of cement to total aggregate. Thus, a 1:2:4 concrete is sometimes designated as a 1:6 concrete.

8. **Required Amount of Water.**—The hardening of cement paste, mortar, and concrete is due to a chemical process that takes place between the cement and the water that is added to the mixture. Sufficient water should be used to permit the completion of the chemical process; this water is entirely assimilated by the masonry and becomes a part of it. If, however, the mixture contains much more water than is necessary for the chemical process, the surplus water is not assimilated by the masonry but remains in the mortar or concrete in the form of drops. In time, the drops evaporate or seep away, leaving voids in their places, which are a source of weakness to the concrete. Hence, too much water reduces the strength of the concrete.

Investigations indicate that, for given ingredients and conditions of mixing, the strength of concrete is increased as the *water ratio*, or the ratio of the volume of mixing water to the volume of cement, is diminished, provided the mixture obtained is plastic and workable. It is a good rule to make concrete just wet enough to flow like a stiff, yet plastic, paste into the recesses of the forms or down the chutes used for its conveyance. In wet mixtures the heavier particles are liable to separate out and settle to the bottom.

PLAIN, OR MASS, CONCRETE

9. **Application of Plain Concrete.**—Plain, or mass, concrete is concrete in which reinforcing steel is not employed. It is used in the more bulky parts of a structure, such as footings and foundation walls of buildings, and in massive structures

such as dams and retaining walls. Plain concrete is also employed in sidewalks, pavements, and basement floors.

10. Plain-Concrete Footings and Walls.—The footings used in construction are mainly *column* or *pier footings*, and *wall footings*.

The simplest type of column or pier footing is shown in Fig. 1; it consists of a single concrete layer *a*. Upon this layer is built the column or pier *b*. The depth *d* of the footing is determined by the amount of the projection *c*.

FIG. 1

As a rule, in plain footings the depth *d* should not be less than twice the projection *c*. Plain-concrete footings for columns

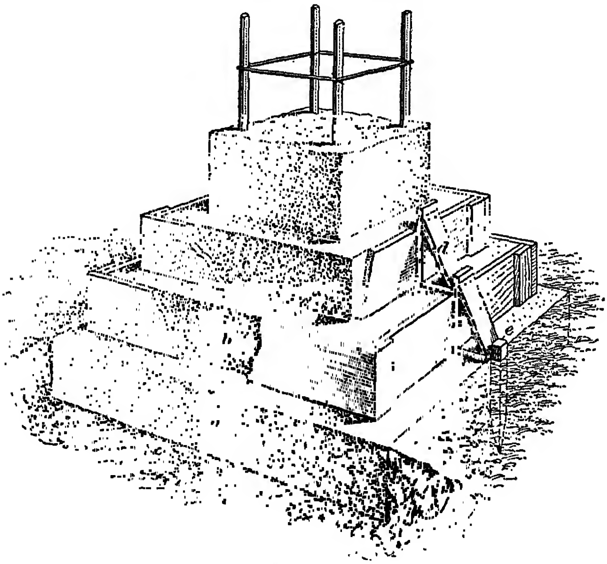


FIG. 2

that carry heavy loads are usually built in steps, as shown in Fig. 2, in order to save concrete.

A concrete wall footing is a layer of concrete placed on the soil to provide support for a wall which may be of either con-

crete, stone, or brick. The depth of wall footings should not be less than twice the projection of the footing beyond the face of the wall. In Fig. 3 is shown a section through a plain-concrete cellar wall that is supported by a plain-concrete wall footing *a*.

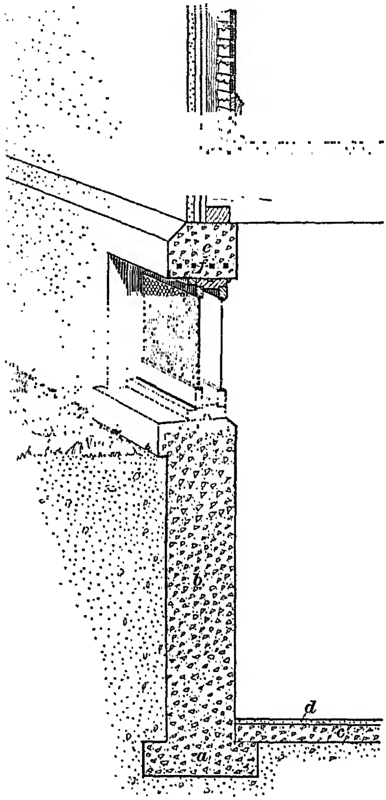


FIG. 3

A good illustration of a plain-concrete wall is the cellar wall *b* in Fig. 3. The part of the wall above the ground contains the windows that give light to the cellar. Above each window is the concrete lintel *e*, which is reinforced by means of the bars *f* shown in section. At *c* is shown a plain-concrete cellar floor that is provided with a cement-mortar wearing surface *d*.

11. Forms for Plain-Concrete Footings and Walls.—In a firm soil it is not necessary to use a form for the construction of a footing like that shown in Fig. 1; a space of the exact size of the footing is generally excavated and filled with concrete. When the soil is so loose that the sides of the excavation will not remain vertical, wooden forms are used. Such forms can be built of four boards nailed together in the shape of a box. Stakes, which are usually driven in the ground outside the form, serve to hold the form in place and to prevent the sides from bulging when the concrete is poured.

The form for a footing such as shown in Fig. 2 is made in sections. Where soil conditions permit, the mold for the lowest part *a* of the footing is made in the soil without the use of wood; but, if the sides of the excavation will not stand up, board forms must be used. The forms provided for the sections *b* and *c* are as shown in the figure. These forms are held in place by the braces *d*, which are fastened to the stakes *e* and to the forms.

A typical form for a plain-concrete wall of considerable height is shown in Fig. 4. It consists of 4″×4″ upright posts *a*, spaced 2 to 3 feet apart, to which are nailed the planks *b*. The uprights are held together by means of the wires *c*, which pass between the planks and are looped about the uprights. The wires are made taut by twisting with a stick *d* so that the forms bear firmly against the wood-block spacers *e*. Spacers *f* are also used at the top to keep the forms the proper distance apart.

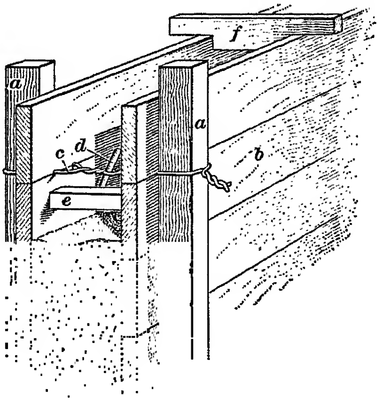


Fig. 4

REINFORCEMENT

12. Purpose of Reinforcement.—Concrete is sufficiently strong in compression to make it a desirable building material, but it is weak in tension. In fact, the tensile strength of concrete is from one-sixth to one-tenth of its compressive strength. The weakness of concrete in tension is remedied by the addition of steel reinforcement, which is so placed as to take care of the tensile stresses most effectively. Thus, concrete reinforced with steel becomes available for many types of structures that could not be built of plain concrete. It is in the construction of beams and similar members which are subject to bending that reinforced concrete is most advantageously employed, because

when a beam supports a load it is bent so that one side is elongated and the other compressed; the elongated or tension side is therefore reinforced with steel rods or bars. However, reinforced concrete is also used in the construction of structures that are entirely in tension, such as tanks, and in structural members that are entirely in compression, such as columns.

13. Types of Reinforcement.—The steel reinforcement for concrete construction may be in the form of plain or deformed rods or bars, sheet metal that has been cut and spread out into what is known as *expanded metal*, and wires that have been woven or welded together to form what is known as a *wire fabric*.

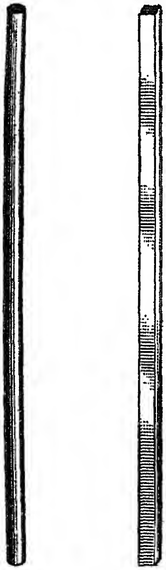

(a) (b)

Fig. 5

14. Plain Rods and Bars.—Plain round or square steel bars, shown in Fig. 5, are most used, because they offer the cheapest and most available form of steel reinforcement. Their price per pound is lower than for any other form of rolled steel, and the usual sizes can be obtained at short notice from the stock of dealers or mills. The areas and perimeters of the more commonly used sizes of plain round and square steel bars are given in Table I at the end of this Section. The plain round rods, shown in Fig. 5 (*a*), are usually called *rods*, while the plain square rods, shown in (*b*), are often called *bars*. In engineering literature both the round rods and square bars are referred to as bars or as rods without distinction, and in the following pages the same practice will be followed. Rectangular bars, called *flats*, or *flat bars*, are sometimes employed for the reinforcement of circular structures, as hoops for columns.

The price of plain bars is based on their sizes. $1\frac{1}{2}$-inch to $\frac{3}{4}$-inch bars are sold at the lowest rate, which is known as the *base price*. For the smaller sizes there is an extra charge above base price. This extra charge is called the *size differential*, which increases as the size of the bar decreases.

15. Deformed Bars.—A steel bar embedded in concrete offers considerable resistance to being pulled out. The resistance is due to the adhesion, or *bond*, between the concrete and steel. This bond is improved by deforming the bar.

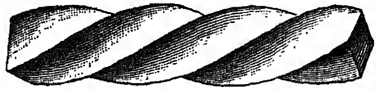


FIG. 6

The simplest and cheapest type of deformed bars is the *twisted bar*, illustrated in Fig. 6, which is made by twisting a square bar in a cold state. When the rolling mills are not running to capacity, and the supply of steel exceeds the demand, there is no charge for twisting, but usually a small charge is made for the extra work.

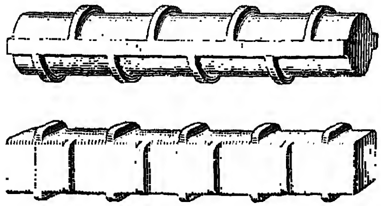


FIG. 7

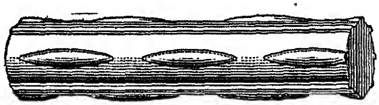
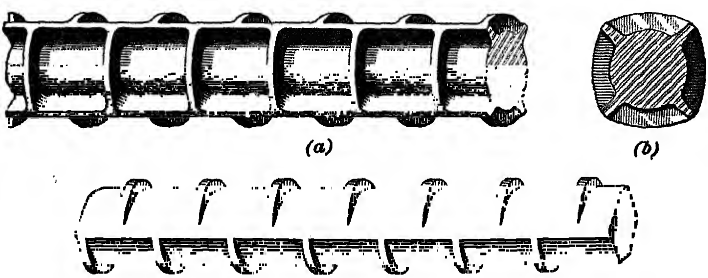


FIG. 8

The bars shown in Fig. 7 are known as *corrugated bars*. They are formed with projections on all sides and are furnished



(a)

(b)

(c)

FIG. 9

in either round or square steel by the Corrugated Bar Company, Buffalo, New York.

In Fig. 8 is shown a *Havemeyer bar*, which is made with longitudinal projections or fins. Havemeyer bars are made

round or square in section. They are furnished by the C
crete Steel Company, of New York.

In Fig. 9 (*a*) and (*b*) are shown a perspective and cross-
tion of a *Kahn cup bar*, which is a round rod with longitud

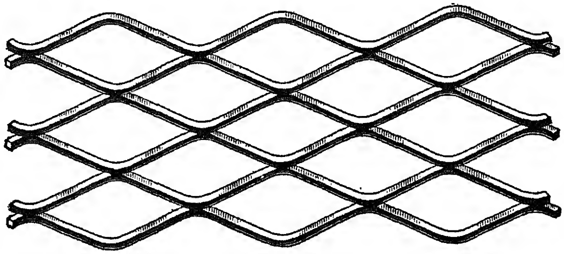


FIG. 10

and transverse ribs. The bar shown in (*c*) is known as
Kahn rib bar. Both bars are produced by the Truscon S
Company, of Youngstown, Ohio.

16. Expanded Metal.—One of the oldest forms of r
forcement for concrete is expanded metal, which is u

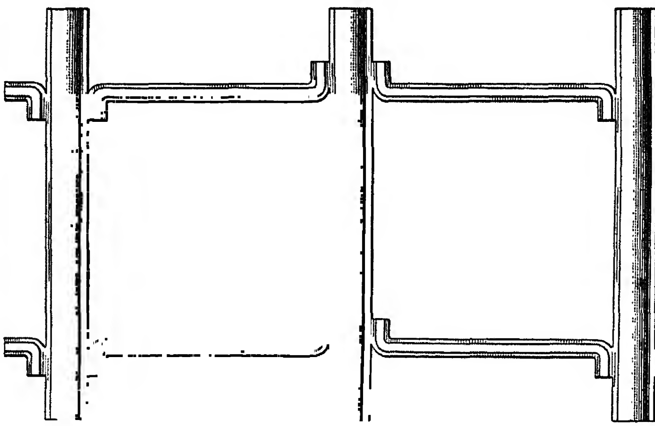
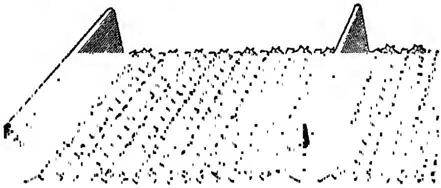


FIG. 11

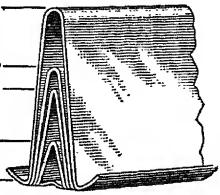
principally for the reinforcement of slabs. There are vari
forms of expanded metal on the market.

In Fig. 10 is illustrated a form of expanded metal tha
known as *steelcrete*. This reinforcement is manufacturec

sheets 4 to 7 feet wide and in lengths of 8, 10, 12, and 16 feet. The meshes, or diamonds, are formed in different sizes and the



(a)

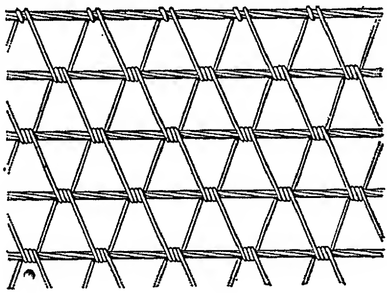


(b)

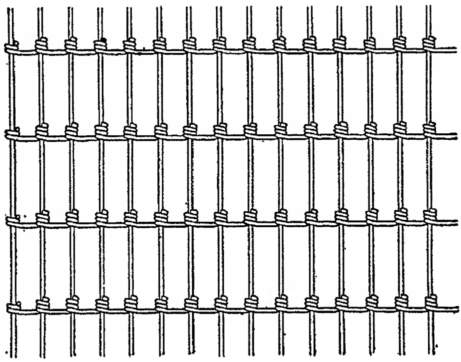
Fig. 12

metal is made in different thicknesses, according to the use to which the reinforcement is to be put. The 3″×8″ mesh, however, is the standard mesh of steelcrete used in concrete reinforcement, the smaller meshes being used for other purposes, such as metal lath. In using steelcrete, the sheets are placed so that the long dimension of the diamonds is in the direction of the short span of the slab.

Another form of expanded-metal reinforcement for slabs is the *Kahn rib metal* shown in Fig. 11. In this type of reinforcement the heavy bars of the section act as main reinforcing bars, while the light cross-bars act as spacing bars. The meshes vary from a 2-inch mesh, in which the main reinforcing bars are placed 2 inches



(a)



(b)

Fig. 13

center to center, to an 8-inch mesh, in which these bars are placed 8 inches center to center.

There are many other forms of expanded metal on the market. The form illustrated in Fig. 12 (*a*), known as *Hy-Rib*, is a metal lath stiffened with rigid ribs made of the same sheet of steel. Hy-Rib is made in several heights, as shown in (*b*), and in flat or curved sheets in lengths of 6, 8, 10, and 12 feet. It is suitable for reinforcing floors, partitions, ceilings, and roofs.

17. Wire Fabric.—For the reinforcement of slabs, wire fabrics are frequently used. These are made by weaving or welding together wires into triangular or rectangular meshes. Wire fabrics are usually constructed with heavy or closely spaced wires, known as *carrying wires*, on which the strength of the reinforcement depends; and these wires are held in their proper positions by lighter wires, known as *transverse wires*, that complete the fabric. Drawn wire of high tensile strength is used for making wire fabric.

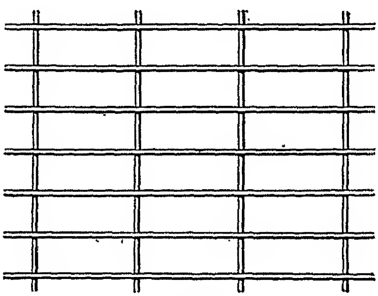


FIG. 14

In Fig. 13 are shown two forms of woven-wire fabrics: one with a triangular mesh in (*a*), and one with a rectangular mesh in (*b*). In both forms, the carrying wires are woven mechanically with the transverse wires. The carrying wires often consist of several wires twisted together in the form of cables, as in (*a*).

In the wire mesh shown in Fig. 14, the carrying and transverse wires are securely welded together at their intersections. A solid and substantial union between the wires is thus obtained.

TYPES OF REINFORCED-CONCRETE BUILDINGS

18. From an architectural point of view, buildings of reinforced concrete may be classified, according to the extent to which reinforced concrete is employed in their construction, into the following three groups: (1) Those in which the entire structure is built of reinforced concrete; (2) those in which reinforced concrete is used only for the framework, or skeleton; (3) those in which only the floor slabs are of reinforced concrete. From an engineering point of view, buildings con-

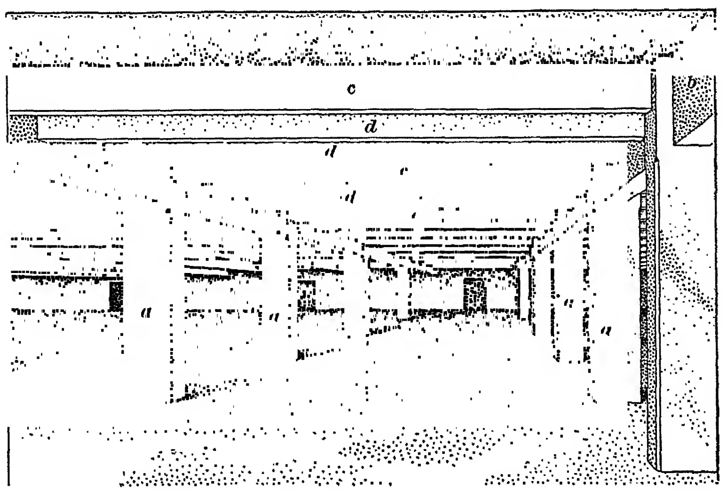


FIG. 15

structed of reinforced concrete are classified, according to the principal features of the floor construction, into the following two main types: (1) *Beam-and-girder construction*, and (2) *flat-slab construction.*

19. In Fig. 15 is shown a perspective of the interior of a building of beam-and-girder construction. The columns *a* support the girders *b* and beams *c*, while the girders support the beams *d*. Over the beams and girders extend the slabs *s*, which constitute the floor.

20. In flat-slab construction the beams and girders are omitted and the floor consists of a flat slab that rests directly upon the columns. In Fig. 16 is shown a perspective of the

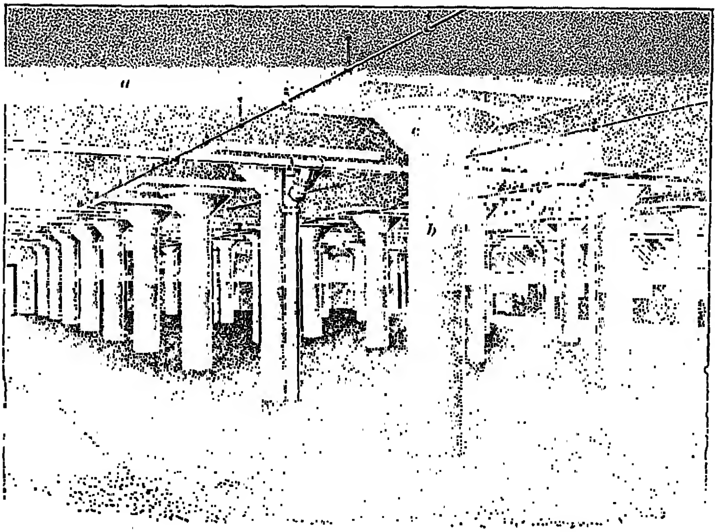


FIG. 16

interior of a building of flat-slab construction. The floor is composed of a slab *a*, which extends continuously over the columns *b*. The columns are usually flared out at the top to form what are known as *column capitals*, *c* in Fig. 16.

BEAM-AND-GIRDER CONSTRUCTION

TYPICAL DETAILS OF MEMBERS

BEAMS

21. Tension Reinforcement.—When a simple beam is loaded, it deflects in the manner shown in Fig. 17. The material at the bottom of the beam is stretched and is therefore in tension, while that at the top of the beam is shortened and is in compression. If the beam were constructed of plain concrete, it would fail under heavy loads in the manner shown in Fig. 18, because concrete cannot resist much tension,

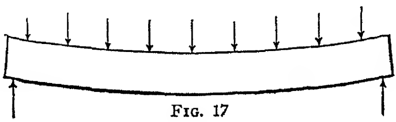


FIG. 17

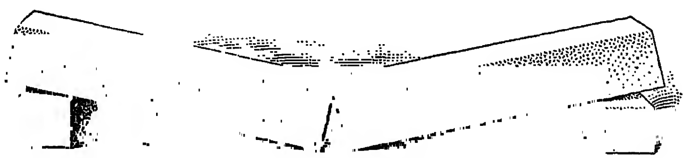


FIG. 18

although it can withstand considerable compression. However, if steel rods are inserted near the bottom of the beam, as shown at *a*, Fig. 19, in elevation in (*a*) and cross section in (*b*),

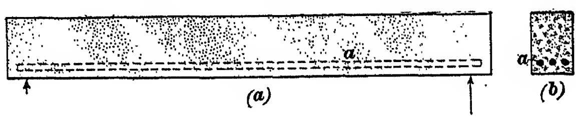


FIG. 19

the beam can carry much heavier loads, because the steel rods then resist the tensile stresses in the beam, while the concrete

resists the compressive stresses. These steel rods constitu
the *tension reinforcement* of the beam.

A beam reinforced as in Fig. 19, if loaded to the breaki
point, usually fails at the center, where the deflection is grea
est and where the greatest tensile and compressive stress

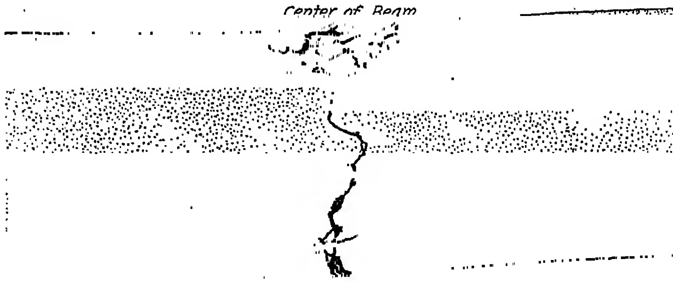


FIG. 20

exist. Immediately before failure, the appearance of the bea
at its center is as illustrated in Fig. 20. Near the top of t
beam the concrete is crushed, while near the bottom is
wide crack that indicates excessive elongation in the roc

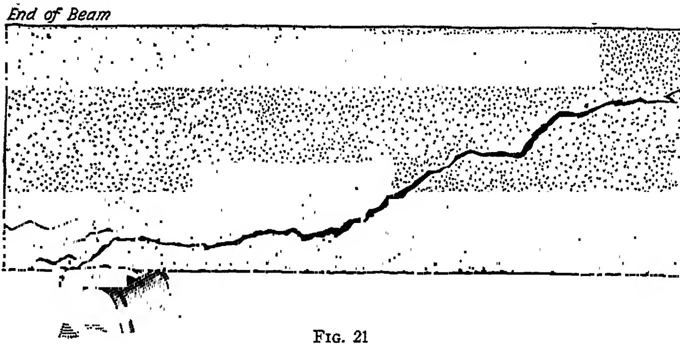


FIG. 21

Ultimately, either the concrete near the top of the beam con
pletely crushes or the rods near the bottom break.

22. Web Reinforcement.—A reinforced-concrete bea
may also fail at the ends, in the manner shown in Fig. 2
because of *diagonal tension*, which is the combined effect of t

tensile and shearing stresses in the beam. To provide against diagonal tension, either vertical or inclined reinforcement, known as *web reinforcement*, is employed.

In Fig. 22 are illustrated the commonly used methods of tension and web reinforcement. In (*a*) the tension reinforce-

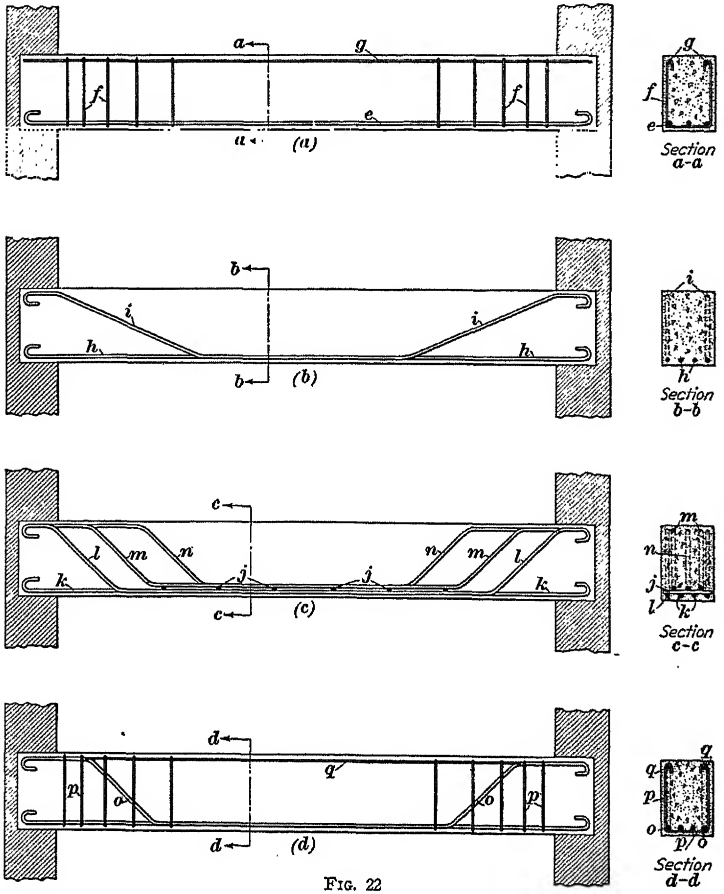


FIG. 22

ment consists of rods *e*, which are straight throughout their length except at the ends, where they are bent into hooks. The purpose of these hooks will be explained later. The web reinforcement consists of light rods *f*, known as *stirrups*, which

are bent to **U** shape; they circle the tension rods and are securely tied to them by means of wires. The stirrups are generally hooked at the ends. The hooks of the stirrups are often tied to light rods *g*, which are used to hold the stirrups in place during construction.

Web reinforcement may also be provided by simply bending the tension reinforcement. In (*b*) the tension reinforcement consists of four rods, of which two rods *h* are left straight and merely hooked at their ends; the other two rods *i*, which are straight and horizontal in the middle of the beam, are bent up at points where web reinforcement is required, are bent horizontally at the edge of the support near the top of the beam, and are hooked at the ends.

Another method of providing web reinforcement without using stirrups is shown in (*c*). The tension reinforcement consists of seven rods, arranged in a lower row of four rods and an upper row of three rods, the two rows being separated by six 1-inch diameter rods *j*. Of the four rods in the lower row, two rods *k* are run straight and are hooked at their ends; the other two rods *l* are bent up at an angle of about 45°, bent again near the top of the beam to run horizontally, and hooked near the ends. The three rods in the upper row are bent in the same manner as rods *l*, first the two outside rods *m* and then the middle rod *n*. These rods are bent at points in the beam where they are no longer necessary to resist horizontal tension and where they are most effective in resisting diagonal tension. Rods bent in the manner indicated in (*b*) and (*c*) form trusses and are known as *truss rods*.

The most effective combination of rods for resisting the stresses in a beam is shown in (*d*), where both truss rods *o* and stirrups *p* are employed. The hooks of the two end stirrups at each end of the beam are wired to the two truss rods *o*, and the other stirrups are wired to the two light rods *q*, which help to keep the stirrups in a vertical position during construction.

23. Double-Reinforced Beams.—Reinforcement is also used occasionally to help resist compressive stresses in beams.

For example, in providing reinforced-concrete beams for a structure, it sometimes happens that the dimensions of a beam are fixed by building conditions and the loads on the beam are so great that it is necessary to employ steel reinforcement not only to resist the tensile stresses near the bottom of the beam but also to help resist the compressive stresses near the top of the beam. Such a beam is known as a double-reinforced beam. In Fig. 23 is shown a typical double-reinforced beam. The tension reinforcement consists of four rods *a*, the compression reinforcement of three rods *b*, and the web reinforcement of stirrups *c*, which circle both the tension and compression reinforcement.

24. T Beams.—All beams considered in the preceding articles have a rectangular cross-section. In reinforced-concrete beams, however, steel has been introduced for the

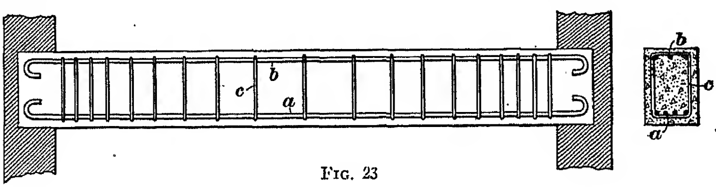


FIG. 23

specific purpose of taking the tension at the bottom of the beam, so that the concrete is no longer needed for that purpose. Some of the concrete in the tension part of reinforced-concrete beams may therefore be omitted without lessening the strength of the beam. The **T**-shaped beam known as a **T** beam, shown in Fig. 24, is thus obtained. In that beam the *stem a* serves to connect the tension steel *r* with the compression part, or *flange b*. The arrangement of reinforcement in **T** beams is similar to that in rectangular beams.

In beam-and-girder floors, part of the slab acts as a compression flange for the beams and girders, so that each beam or girder becomes a **T** beam. In order to obtain the necessary unity of slab and beam or slab and girder, the concrete of the slab, beams, and girders is usually poured in one continuous process. Concrete that is poured so as to form one mass is said to be *monolithic*, the meaning of the word monolithic being *of*

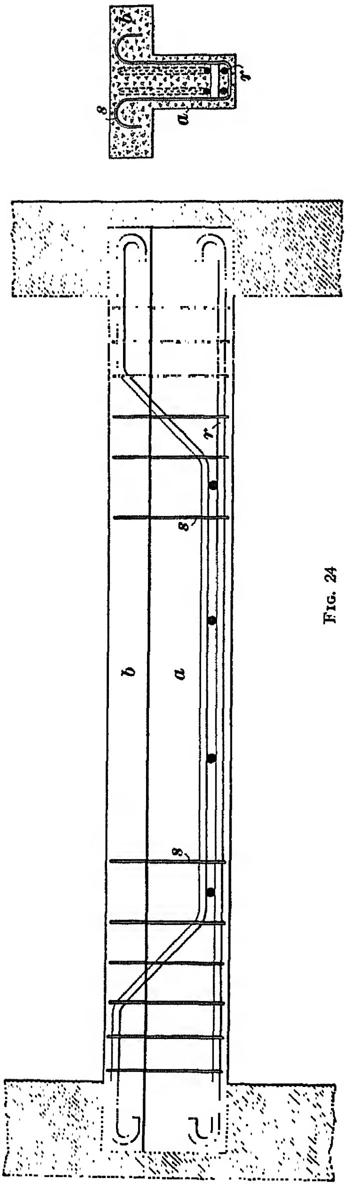


FIG. 24

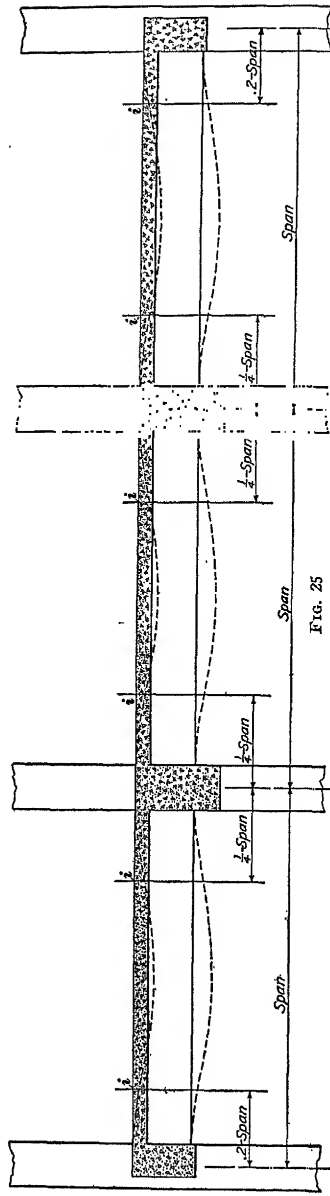


FIG. 25

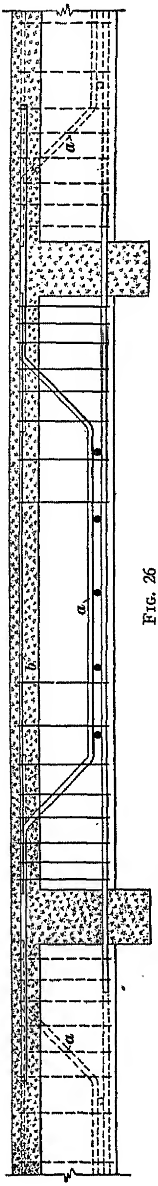


FIG. 26

one stone. The unity of the slab and beam or slab and girder is increased by the stirrups, which are usually bent like the stirrups *s* in Fig. 24.

25. Bending in Beams of Monolithic Structures.—In monolithic structures the beams are fixed at their connections to the other members. Therefore, the beams when loaded deflect in the manner shown in Fig. 25. Near supports the beams bow upwards, while in the middle they bow downwards like simple beams. The points *i* in the beams where the bending changes from upward to downward bowing are known as the *points of inflection*. In uniformly loaded beams these points of inflection are located at a distance equal to about one-quarter of the span length from the centers of intermediate supports and at a distance equal to about two-tenths of the span length from the ends of the end spans.

In the part of the beam between the points of inflection, where the beam bows downwards, tensile stresses occur near the bottom and compressive stresses near the top, in the same manner as in a simple beam. In the parts of the beam between the points of inflection and the supports, where the beam bows upwards, tensile stresses occur near the top and compressive stresses near the bottom. Thus, there is a reversal of stress at the points of inflection, and the tension in the beam passes from the lower part to the upper at those points.

To provide tension reinforcement in the upper part of the beam between the points of inflection and the supports, which is generally known as *negative reinforcement*, one-half the rods near the bottom of the beam are bent up

at the points of inflection at an angle of 45°, bent near the top of the beam, and carried horizontally to the point of inflection in the next span, like rods *a* in Figs. 26. The hooks of the stirrups are tied to the light rods *b* in order to hold the stirrups in place during construction. The reinforcement of the beam under consideration is represented by means of full lines and that of the adjacent beams by means of dash lines.

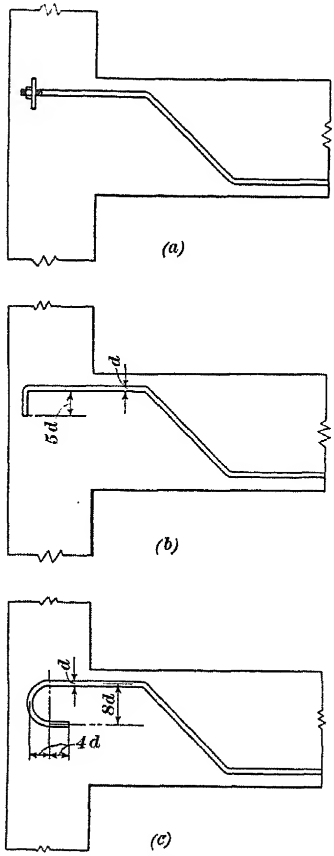


FIG. 27

26. Bond Between Concrete and Steel.—The strength of the bond between concrete and steel is influenced by various factors. Rods with a thin film of rust show a larger bond strength than clean rods, and the strength of the bond between concrete and deformed bars is generally greater than between concrete and plain bars. Some engineers, however, object to the use of deformed bars because the deformations tend to split the concrete when the beam is being stressed. Plain square bars develop about three-quarters of the bond strength normally developed by plain round rods. Flat bars are even less efficient than square bars.

The slipping of rods in concrete is made more difficult, and the bond strength therefore improved, by anchoring the ends of the rods. In Fig. 27 are illustrated three ways of anchoring the ends of rods. In (*a*) the end of the rod is threaded and a washer and nut put on it; an effective, though expensive, anchorage is thus provided.

In (*b*) the end of the rod is bent to a quarter circle with a radius equal to two times the diameter of the rod and continued straight for a short distance, the length of the bent portion being at least five times the diameter of the rod. In (*c*) the end of the rod is bent to a semicircle with a radius equal to four times the diameter of the rod and continued straight for

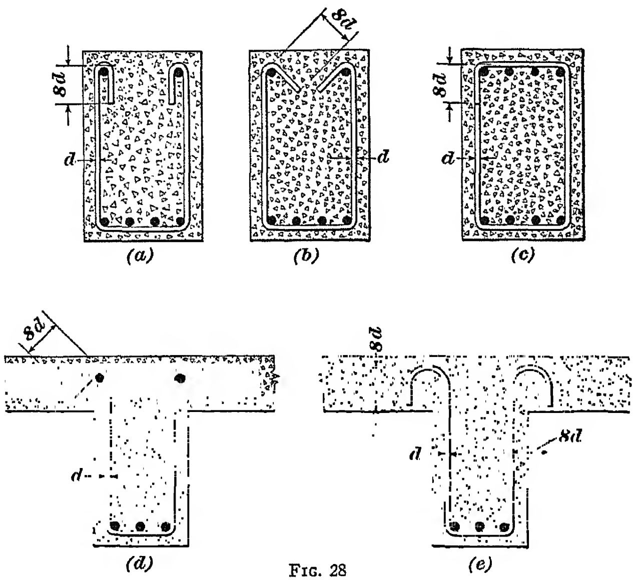


FIG. 28

a distance equal to four times the diameter of the rod, forming a hook. The bend shown in (*c*) is generally considered more effective than that shown in (*b*).

The typical methods of anchoring the ends of vertical stirrups are illustrated in Fig. 28. The methods shown in (*a*), (*b*), and (*c*) apply to rectangular beams, and those shown in (*d*) and (*e*) apply to **T** beams. The stirrup shown in (*c*) is used mainly in double-reinforced beams. Of the various bends shown, those of semicircular shape are the most effective.

SLABS

27. One-Way Slabs.—In the usual type of beam-and-girder construction, the slabs extend between parallel beams, which in turn are supported by girders. In Fig. 29 (*a*) is shown a plan view of a panel of typical beam-and-girder construction; the slab *S* is supported by the beams *B*, which are carried by the girders *G* and the columns *C*. For all practical purposes, slabs may be considered as rectangular beams of comparatively shallow but very wide section. The reinforcement in the slab consists of two types, *principal reinforcement* and *secondary reinforcement*.

In slabs supported as in Fig. 29 (*a*), the principal reinforcement *a* runs parallel with the span and serves to transfer the loads on the slab to the supporting beams *B*. Over the principal reinforcing rods and at right angles to them are placed the secondary reinforcing rods, or *distributing rods*, *b*, which serve to transfer the loads on the slab to the principal rods. The secondary reinforcing rods also help prevent cracks in the concrete due to contraction with changes in temperature or due to shrinkage in setting; therefore, they are often called *temperature reinforcement* or *shrinkage rods*.

Slabs that are reinforced so that the principal reinforcing rods carry the load to supports in one direction only, as in Fig. 29, are known as *one-way slabs*.

In slabs of shallow depth, say 4 inches or less, the main reinforcement consists of straight rods near the bottom of the slab, as rods *a* in (*b*). The distributing rods *b* are placed over the main rods and are wired to them. In slabs of comparatively long spans, negative reinforcement should also be provided in the top of the slab over supports.

As previously mentioned, slabs may also be effectively reinforced by means of expanded metal or wire fabric. In short spans, the sheets of expanded metal or wire fabric are placed near the bottom of the slab, the long dimensions of the diamonds, Fig. 10, or the heavy bars, Fig. 11, in expanded metal, and the carrying wires in wire fabric, Fig. 13, being placed parallel to the span. In longer spans, the expanded-metal or

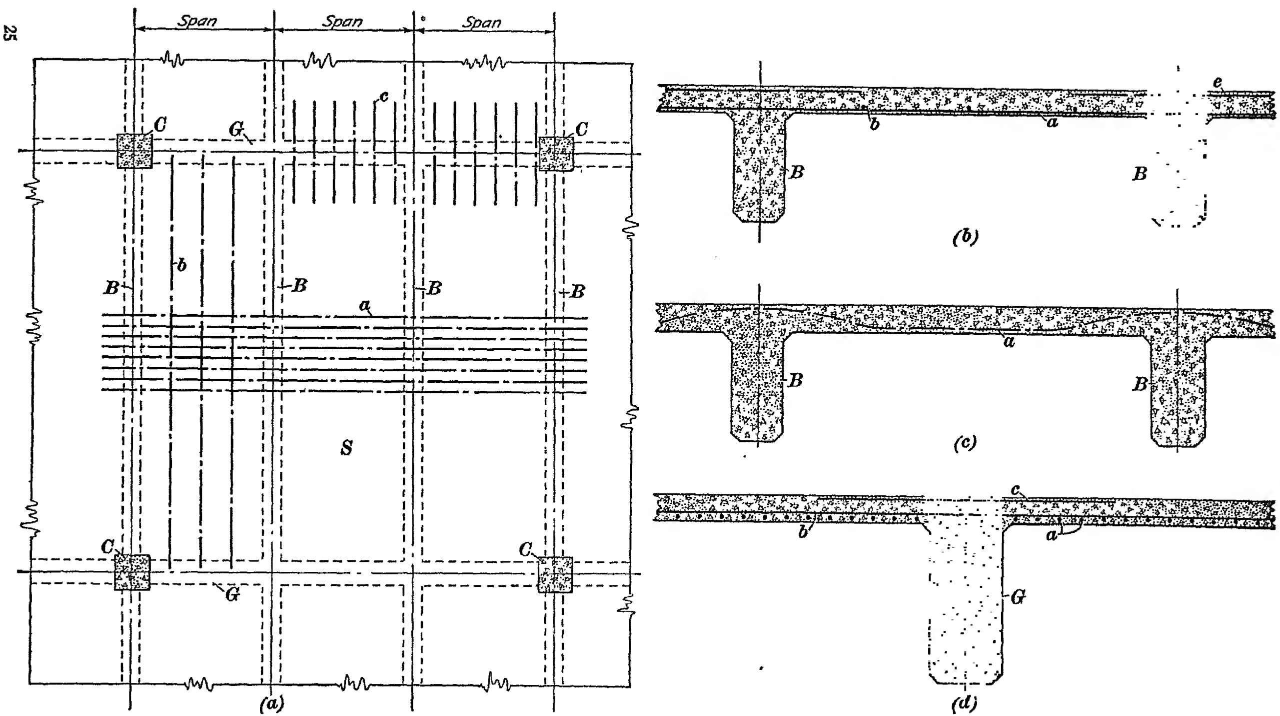


FIG. 29

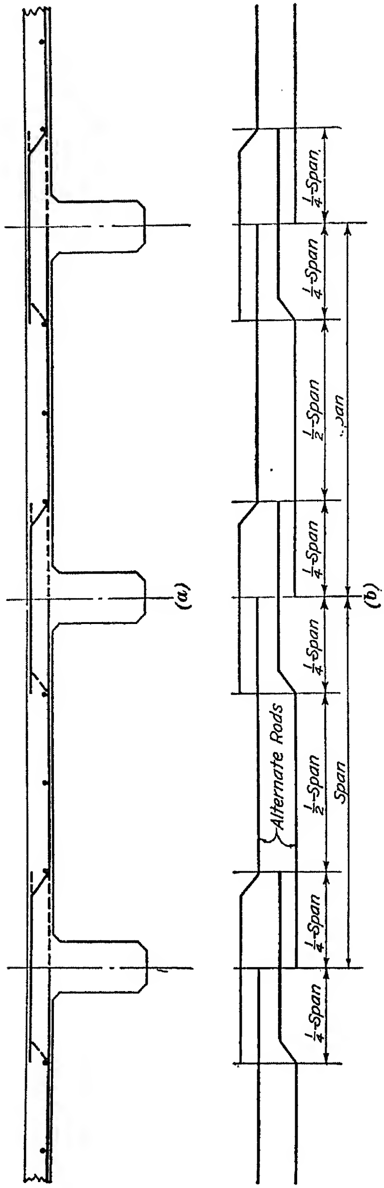


FIG. 30

wire-fabric reinforcement is curved over supports in the manner shown in (*c*), where the reinforcement *a* is curved over the beams *B*.

The beams *B* shown in (*b*) and (*c*) are reinforced in the usual manner, but the reinforcement is omitted by way of emphasizing the details of the slab.

28. Shear Rods. Where a comparatively thin slab connects to a deep girder and the principal reinforcement in the slab runs parallel to the girder, there is a tendency for the slab to break away from the girder. Hence, transverse reinforcing rods are placed near the top of the slab over the girder, as rods *c* in the plan view shown in Fig. 29 (*a*) and in the section through girder *G* shown in (*d*). The rods *c* are known as shear rods. They usually are $\frac{3}{8}$- or $\frac{1}{2}$-inch square or round rods, 4 to 5 feet long, and spaced about 1 foot cen-

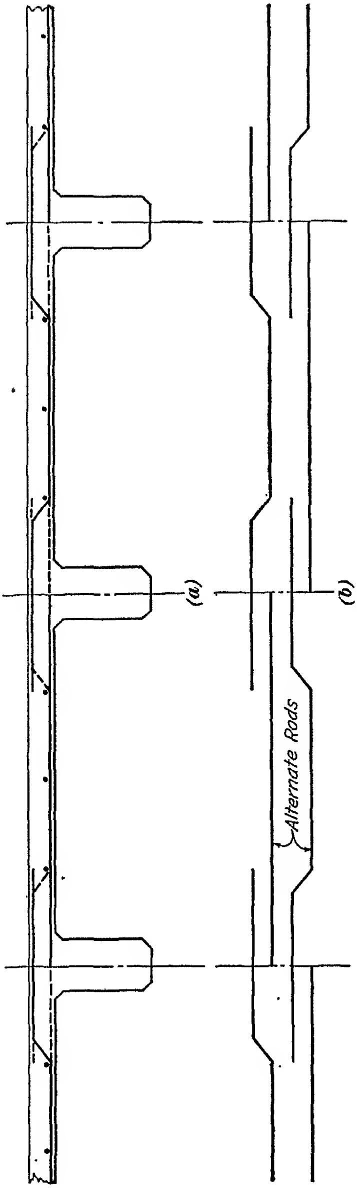


Fig. 31

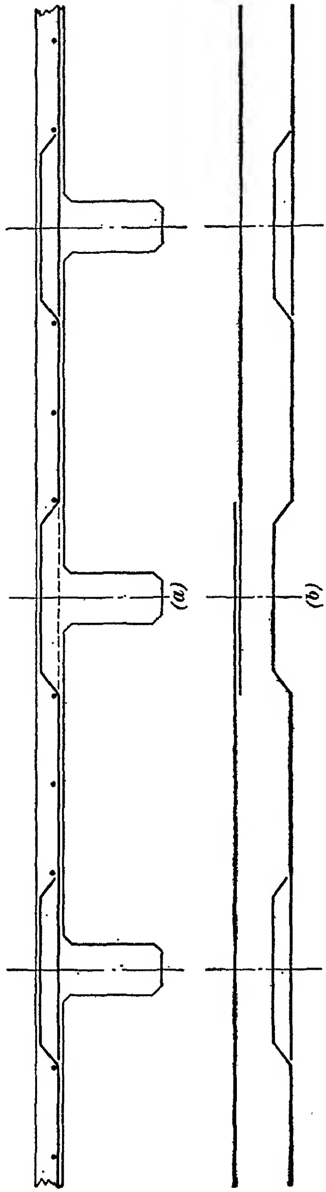


Fig. 32

ter to center. The cross-sectional area of the shear rods should not be less than three-tenths of one per cent. of the cross-sectional area of the slab, and they should be spaced not more than 18 inches apart.

29. Negative Reinforcement.—The simplest way of providing negative reinforcement in slabs is to place short rods over the supports, as indicated by the dashed line *e* in Fig. 29 (*b*). The length of such rods is usually equal to one-half the span of the slab. The objection of this method of reinforcement is that during construction the short rods in the top of the slab are easily displaced. More effective methods of providing negative reinforcement are shown in Figs. 30, 31, and 32.

In Fig. 30 all rods are bent up at one end at a distance from the center line of the beam equal to one-quarter of the span. The angle of bend is usually 30° in shallow slabs and 45° in comparatively deep slabs, and the bent-up portion runs horizontally near the top of the slab to the quarter point in the adjacent span. The reinforcement in the slab is arranged so that the bent portions of the rods in every alternate layer point in the opposite direction to those of the layer preceding it, as indicated by the dashed lines in the cross-section through the span shown in (*a*). A diagram of two adjacent layers of rods is shown in (*b*), where, for the sake of clearness in indicating the arrangement, the rods are shown as if laid down flat and not in true projection. Such a method of representation is *diagrammatic*.

Another method of providing negative reinforcement is illustrated in Fig. 31, where the principal reinforcement consists of alternate straight and bent rods. The bends in the bent rods are made at both ends at the quarter points in the span and are run horizontally near the top of the slab to the quarter points in the adjacent spans. In (*a*) is shown a cross-section through the slab and in (*b*) a diagrammatic representation of the arrangement of two adjacent layers of rods.

To avoid using short lengths of rods, the principal rods may be bent in the manner shown in Fig. 32, in cross-section

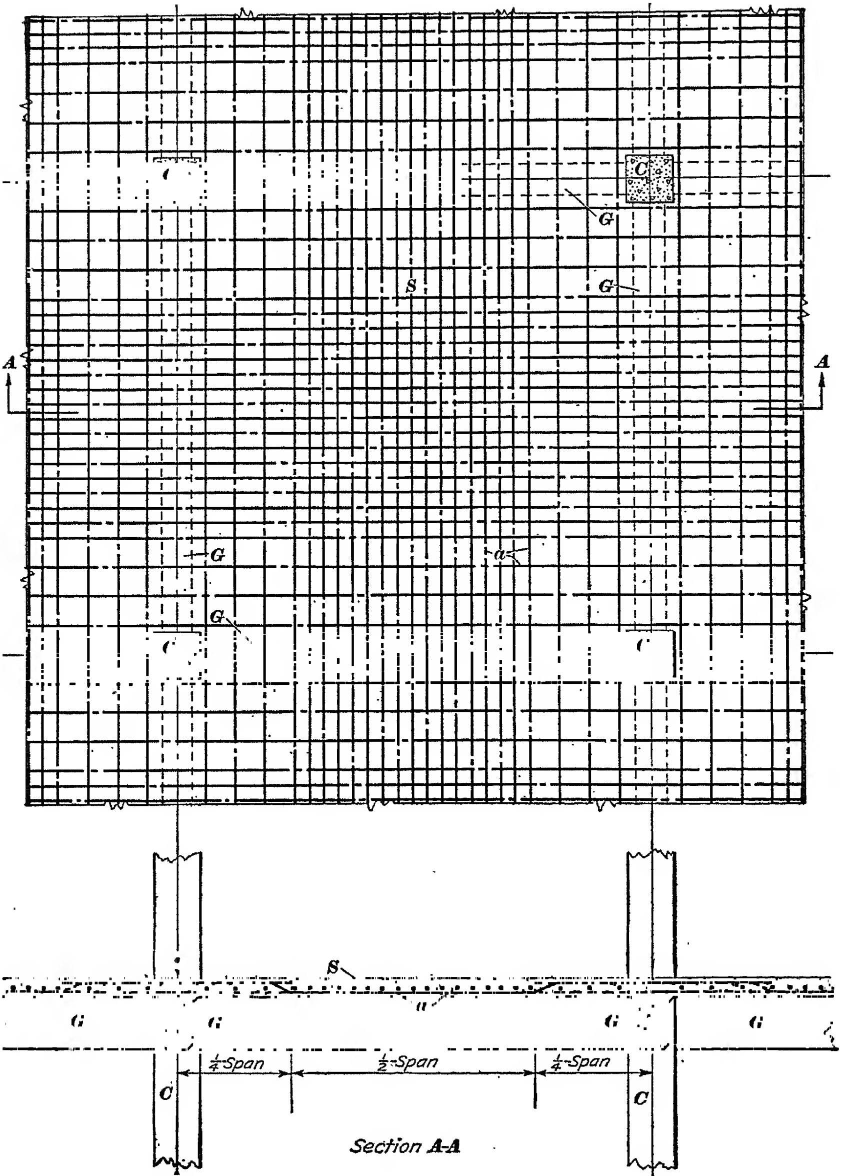


FIG. 33

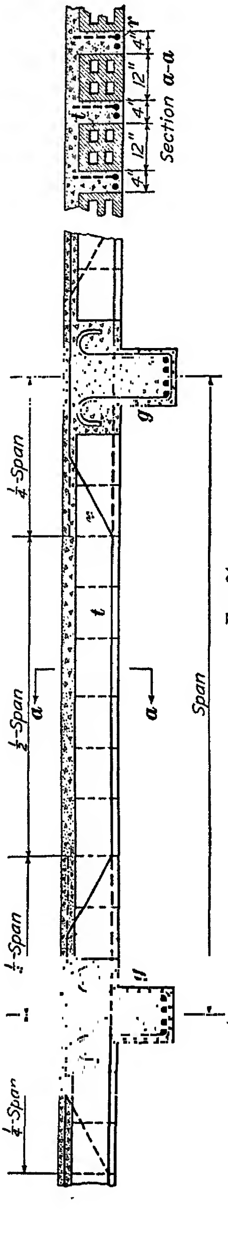


Fig. 34

in (*a*) and in diagram in (*b*). The rods in every alternate layer are left straight.

30. Two-Way Slabs.—Slabs that are square or nearly square and supported along all four sides are constructed with principal reinforcement running in two directions at right angles to each other, as shown in Fig. 33. Such slabs are known as two-way slabs. They are usually supported directly on four girders running between columns. Thus, in Fig. 33 the slab *S* rests on all four sides on the girders *G* that run between columns *C*. The principal reinforcing rods *a* run in two directions and no distributing rods are employed. These rods are spaced closer together near the center of the span than near supports, two-thirds of all rods being placed in the middle half of the span. In two-way slabs, as in one-way slabs, some of the rods are bent at the quarter points of the span to provide negative reinforcement over supports. In Fig. 33 every alternate rod is bent and the other rods are left straight.

31. Tile-Concrete Floors.—The weight of concrete floors is often decreased by substituting rows of terra cotta or hollow tile for part of the concrete in the slab. In Fig. 34 is illustrated typical tile-concrete construction, where reinforced-concrete ribs *r* are constructed between rows of hollow tile *t*. The thickness of the ribs should not be less than 4 inches and the thick-

ness of the concrete spread over the tile should not be less than 2 inches. Hollow tile may be obtained in sizes of 6 in.×12 in. and 12 in.×12 in. in plan that range from 4 to 12 inches in depth. Gypsum hollow blocks are sometimes used instead of terra cotta; the gypsum blocks are usually from 16 to 24 inches wide.

In tile-concrete construction, the tile is considered merely as a filler and the concrete only is relied on for strength, the ribs and concrete over the tile forming a series of **T** beams side by side. The part of the slab next to the girder *g* is made solid in order to increase the compression area in the girder and give it a **T**-shaped form.

32. Concrete Slabs on Steel Beams.—Reinforced-concrete slabs are frequently employed for the floors of buildings in

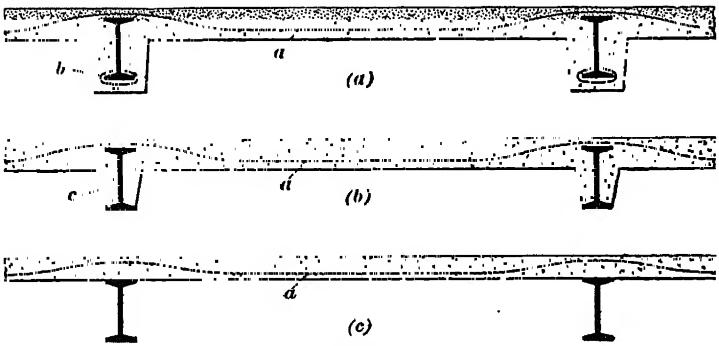


Fig. 35

which the framework is of structural steel. The slabs are then supported on **I** beams in the manner shown in Fig. 35. The **I** beams are either entirely or partly encased in concrete, or are left completely exposed, depending upon the degree of fireproofing desired.

In the construction shown in (*a*), the **I** beam is entirely encased in concrete. To bind the concrete to the steel shape, it is customary to wrap either the entire shape or its bottom flange with wire fabric or expanded metal, as at *b*. In the construction shown in (*b*), the top flange is encased in concrete; the web of the **I** beam is fireproofed with concrete *c*, while the

underside of the bottom flange is exposed. In the construction shown in (*c*), the entire I beam is left exposed. The reinforcement *a* indicated in Fig. 35 is expanded metal or wire fabric. When steel rods or bars are used, the principal reinforcing rods

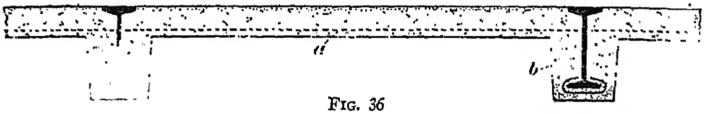


FIG. 36

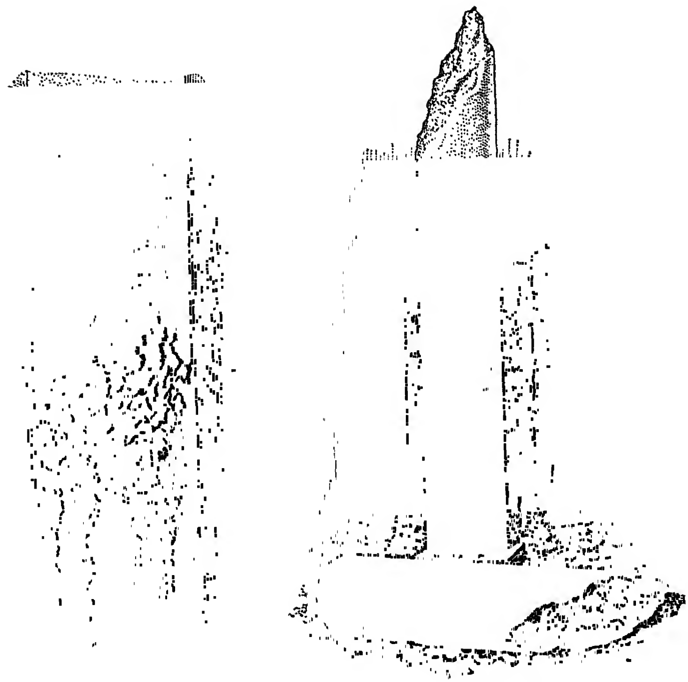
run at right angles to the steel beams and the distributing rods parallel to them, in the same manner as when reinforced-concrete beams are employed.

When conditions require, the concrete slab may be lowered so that its top is flush with the top of the I beams, as in Fig. 36. In such construction, the reinforcement *a* is not continuous but extends from I beam to I beam; the slab is supported on the haunches *b*.

COLUMNS

33. Types of Columns.—Columns may be constructed of either plain or reinforced concrete. A plain-concrete column when loaded until failure occurs, usually fails either by *direct compression* or by *diagonal shear*. A direct compression failure is illustrated in Fig. 37 (*a*); after the ultimate compressive stress of the concrete has been reached, the concrete commences to crush, which is indicated by a flaking or scaling of the outside of the concrete and a gradual shortening or telescoping of the column. A diagonal-shear failure, illustrated in (*b*), is caused by shear along a sloping plane; it occurs suddenly after the ultimate shearing stress of the concrete has been reached.

In modern concrete buildings, plain-concrete columns are rarely employed, reinforced-concrete columns being used almost exclusively. Reinforced-concrete columns may be classified, according to the manner in which they are reinforced, into the following three types: (1) *Columns with lateral ties*, Fig. 38, provided with vertical rods *a* and horizontal ties *b*; (2) *spiral columns*, Fig. 39, provided with vertical rods *a*



(a) (b)

Fig. 37

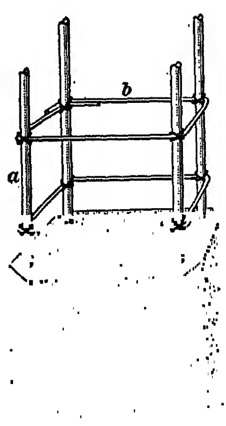


Fig. 38

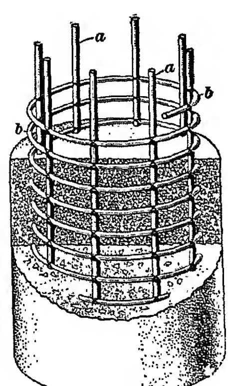
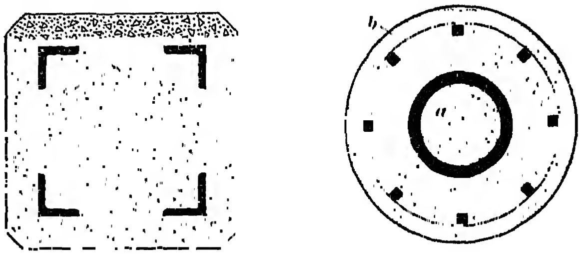


Fig. 39

and spirally wound hoops *b*; and (3) *composite columns*, Fig. 40 plain- or reinforced-concrete columns in which are embedded structural-steel shapes or cast-iron cores.

Reinforced-concrete columns are also classified, according to the position they occupy in the structure, into *interior columns* and *wall columns*.

34. Columns With Lateral Ties.—The vertical rods *a* in Fig. 38 are usually plain round or square rods, deformed bars being seldom employed as column reinforcement. The horizontal ties *b* are generally made of light round rods and sometimes of light flat bars. When a column with vertical rods and horizontal ties is tested to destruction, it fails in the manner



(a) (b)

FIG. 40

shown in Fig. 41; the concrete crushes and spalls out while the vertical rods *a* buckle. Since it takes heavy loads to buckle steel bars embedded in concrete, it is evident that the rods in reinforced-concrete columns carry considerable load and make the column much stronger than a plain-concrete column of equal sectional area. From the nature of the failure, it is also evident that the ties help keep the vertical rods from buckling and prevent the concrete from spalling. Hence, they play an important part in strengthening the column, and the closer they are spaced the stronger is the column. In good construction, the ties should be not less than $\frac{1}{4}$ inch in diameter. They should be spaced not farther apart than 8 inches if of $\frac{1}{4}$-inch diameter and 12 inches if of $\frac{3}{8}$-inch diameter or more, and should be securely wired to the vertical rods. Some specifications require a minimum spacing of 8 inches in all cases.

35. Spiral Columns.—In columns reinforced with vertical rods and closely spaced spirally wound hoops, as in Fig. 39, the vertical rods are well protected against buckling and the concrete against spalling. Such columns are stronger than columns reinforced with vertical rods and ties. The vertical reinforcement *a* for spiral columns usually consists of plain round or square rods, while the spirals *b* are composed of round rods of $\frac{1}{4}$- to $\frac{1}{2}$-inch diameter, or of flat hoop iron 1 inch to $1\frac{1}{4}$ inches wide and $\frac{1}{4}$ to $\frac{3}{8}$ inch thick. The pitch, or spacing, of the spirals should be not greater than one-sixth of the diameter of the hoops and in no case more than 3 inches.

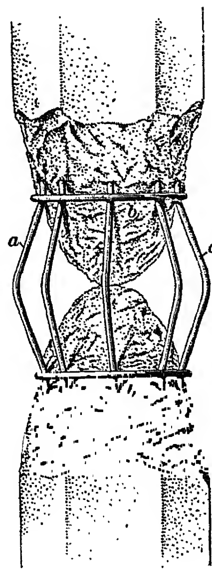


FIG. 41

36. Composite Columns.—A composite column is not really a reinforced-concrete column, because the embedded steel or cast-iron core is relied on to carry the greater part of the load on the column and not much dependence is placed on the concrete. The employment of steel shapes in concrete columns, as shown in the section in Fig. 40 (*a*), greatly increases the cost of the column and makes the connection of the concrete floor to the columns rather difficult. Hence, steel shapes are used only when building conditions make it necessary to reduce materially the size of the columns.

Columns reinforced with cast-iron cores are not used extensively in this country. An efficient type of such column is shown in section in (*b*); it is reinforced with a cast-iron core *a*, spiral hooping *b*, and vertical rods.

37. Typical Column Sections.—The *interior columns* of reinforced-concrete buildings are generally made either square, octagonal, or circular in section. In Fig. 42 are shown sections of the three types of columns: A section of a square column reinforced with vertical rods and square ties is shown in (*a*);

a section of an octagonal column reinforced with vertical rods and circular ties is shown in (*b*); and a section of a circular column reinforced with vertical rods and spiral hooping is shown

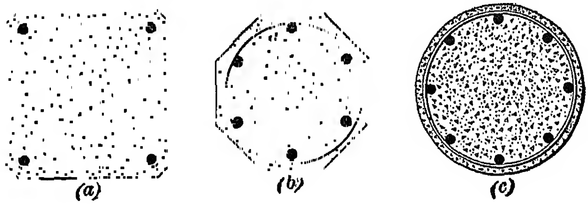


Fig. 42

in (*c*). The ends of the ties in (*a*) are bent in the same manner as those of the ties shown in Fig. 38. The ends of the circular

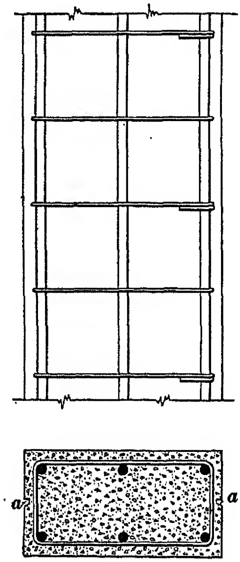


Fig. 43

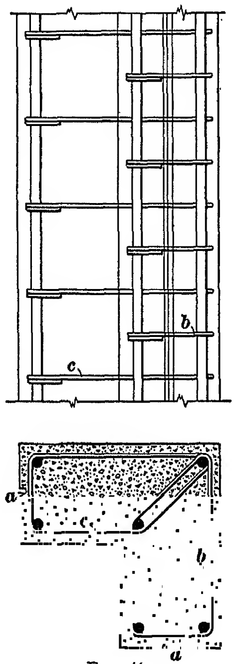


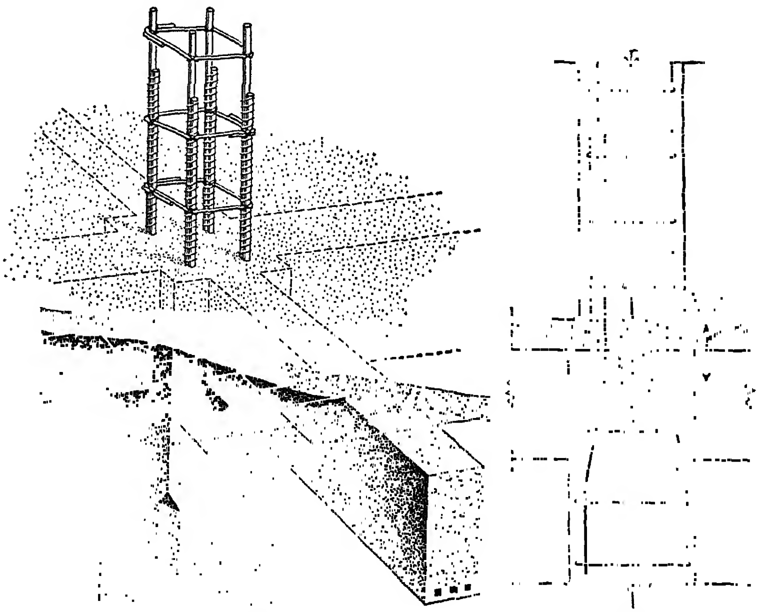
Fig. 44

ties in (*b*) are bent along radii of the circle, as shown at *a*.

The *intermediate wall columns* of reinforced-concrete buildings are usually made rectangular in section. A cross-section

and part elevation of an intermediate wall column are shown in Fig. 43. The reinforcement of such columns usually consists of vertical rods and horizontal ties. The recesses *a* in the sides of the column are provided for the connection of metal window sash, as will be explained later.

For the construction of the *corner columns*, an **L**-shaped section is generally adopted. A part elevation and cross-



(a) (b)

Fig. 45

section of a light corner column are illustrated in Fig. 44. The ties *b* and *c* in the two legs of the section are generally staggered as shown in the elevation.

38. Column Splices.—In the construction of reinforced-concrete columns, provision must be made for splicing the reinforcement of the column in each story with that of the column in the story immediately below. This is usually done near the floor level. The commonly used methods of splicing

column reinforcement are: (1) Lapping the rods, (2) butting the ends of the rods inside sleeves, and (3) drawing the rods together by means of threaded sleeves.

When the vertical reinforcing rods of the column are not more than $\frac{7}{8}$ inch square or 1 inch round, they are spliced by lapping in the manner shown in Fig. 45 (*a*). In such construction, the rods of each column usually start at the floor or foundation level and project a distance equal to 50 times their diameter for plain rods and 40 times for deformed bars beyond the floor level of the story above. Thus, the rods of the columns in the two stories lap 50 diameters if they are plain and 40 diameters if they are deformed; such lap is sufficient for transferring the loads carried by the rods in the upper column to those of the lower column. The lapped portions of the rods should preferably be wired together as shown in (*a*).

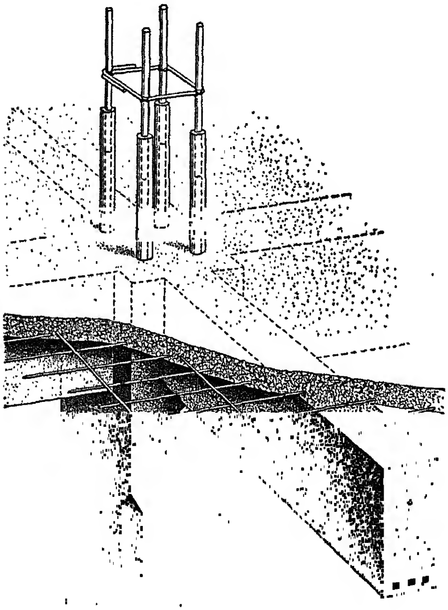


Fig. 46

When the column in the upper story is of smaller dimensions than the column in the lower story, it is necessary to bend the rods below the splice line so that the rods projected from the lower story will be in contact with those in the upper column, as shown in (*b*). Such offsets should be at least 1 foot below the splice and at an angle not greater than 30° with the vertical.

Rods heavier than $\frac{7}{8}$ inch square or 1 inch round are usually spliced by means of plain or threaded sleeves. When the

columns are not subject to tensile stress, which is usually the case in reinforced-concrete construction, the ends of the rods are milled to bear and, as shown in Fig. 46, are fitted into pipe sleeves about 2 feet long and of a diameter enough larger than the rods to render the fitting easy. The main purpose of the sleeves is to hold the rods in place. When the columns are subject to tensile stress, as is sometimes the case, the splicing of the heavy reinforcing rods is often accomplished by threading their ends and drawing them together by means of threaded sleeves.

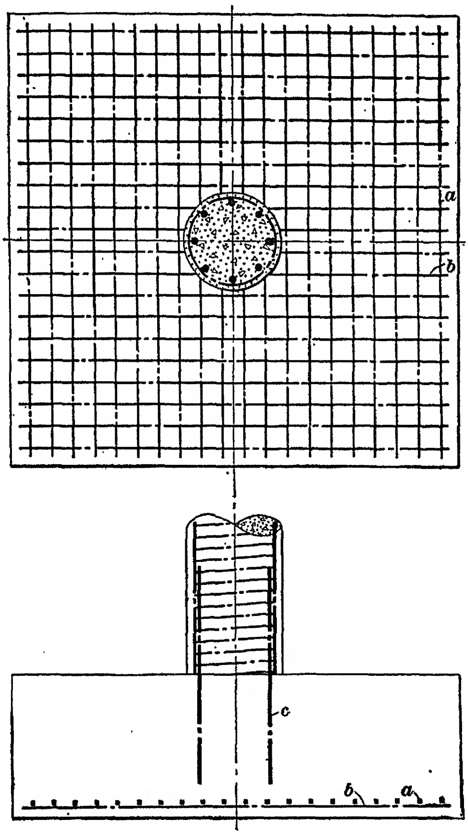


Fig. 47

39. Column Footings.—Reinforced-concrete columns that carry light loads on firm soils are supported by plain-concrete footings, as in Fig. 1. When the column loads are heavy or the soils are relatively soft, the columns are generally supported by reinforced-concrete *spread footings*. In the usual construction, each column has a separate footing, which is known as an *independent column footing*. Sometimes, building conditions make it necessary to support two or more columns on one footing, known as a *combined column footing*.

Reinforced-concrete spread footings for the support of single columns are usually made in one of three forms: (1) *Slab footing*, (2) *sloped footing*, and (3) *stepped footing*. In the slab footing, shown in Fig. 47, the column rests directly on a reinforced-concrete slab. In the sloped footing the top of the footing slab slopes, as shown in Fig. 48. The stepped footing, shown in Fig. 49, consists of a reinforced-concrete slab and one or more steps poured monolithically. The usual way of reinforcing a concrete footing for the support of a single column is by means of two layers of rods, *a* and *b* in Fig. 47, which are placed near the bottom of the footing at right angles to each other and parallel to the sides of the footing. Both layers consist of rods of the same size that are usually placed at equal distances apart. The ends of the rods are either straight as in Fig. 47 or hooked as in Figs. 48 and 49.

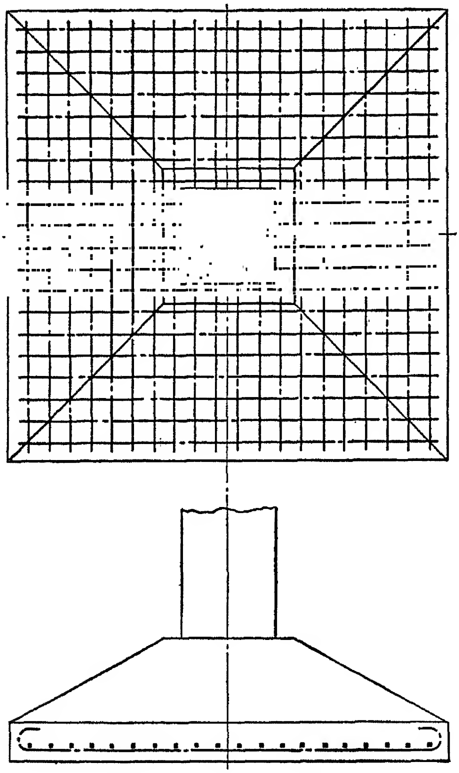


FIG. 48

In the construction of reinforced-concrete footings, the columns are often supported on pedestals, *p* in Fig. 49, which in turn rest on the footings. The pedestal constitutes part of the footing and is constructed of either plain or reinforced concrete.

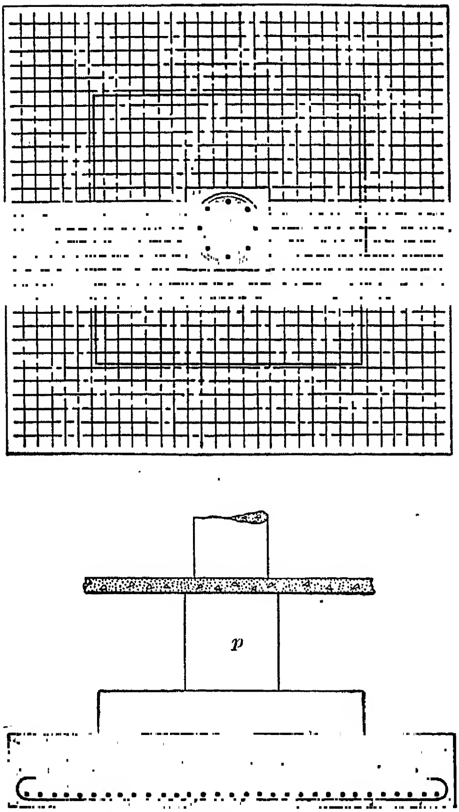


FIG. 49

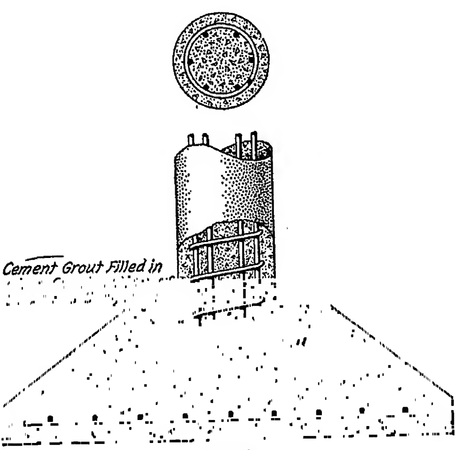


FIG. 50

41

The stress carried by the vertical rods of the column can be effectively transferred to the footing by means of short rods, *c* in Fig. 47, which are embedded in the footing and column, and are known as *dowels*. At least one dowel for each vertical rod in the column should be used, and the total cross-sectional area of the dowels should equal the total cross-sectional area of the vertical rods. The dowels should project into the columns and into the footings a distance not less than 50 times the diameter of the vertical column rods if they are plain rods, and 40 times that diameter if they are deformed bars. When the footing is comparatively shallow and the dowels cannot project the specified distance, the ends of the dowels are hooked in order to provide additional bond strength.

Metal distributing bases, consisting of steel plates, cast-iron chairs, or steel grillage beams are sometimes employed to transfer the column loads to the footing, especially when these loads are heavy. In Fig. 50 the load from the column is transferred to the footing by means of a steel plate *a*.

FORMS FOR BEAM-AND-GIRDER CONSTRUCTION

40. General Considerations.—The forms for reinforced-concrete structures are built in many different ways. The method chosen in a particular case depends upon the type of construction, preferences of the contractor, and various economic considerations. The forms are an expensive item in reinforced-concrete construction. It is therefore important that structures be designed so that one set of forms can be used several times. To allow the repeated use of forms, the beams and girders of the various floors should be made of the same dimensions and be located in the same relative positions.

The forms for buildings of beam-and-girder construction are generally made of timber. Metal forms are also used, especially in the construction of long heavy walls.

41. Typical Illustrations of Form Work.—In Fig. 51 is illustrated a simple type of form work employed in beam-and-girder construction. The forms for the beams frame into the

forms for the girders. At the end of each panel the beam and girder forms are supported by the column forms, and at intermediate points by $4'' \times 4''$ studs *a* that rest on footing pieces *b*. The elevation of the bottom of the studs may be adjusted by means of the wedges between them and the footing pieces. Over the tops of the studs are placed $4'' \times 4''$ bearing pieces which are braced by means of $\frac{7}{8}'' \times 4''$ braces *c*.

The sides of the forms for the columns are built of $1\frac{1}{2}$-inch or 2-inch planks *d*, which are held together by the battens *e*

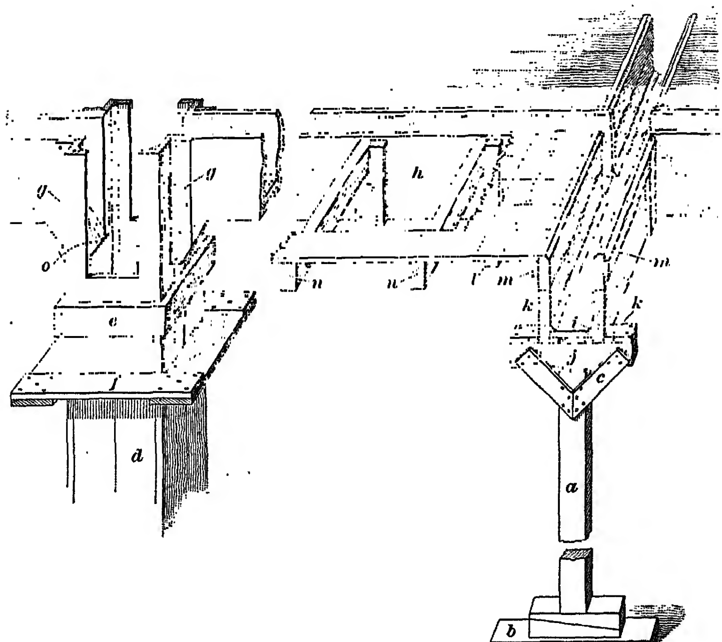


FIG. 51

nailed to them at intervals. The planks are also nailed along the edges and are further secured against spreading by the braces, or yokes *f*. At the top, the column forms have rectangular openings into which the beam and girder forms fit, so that when the concrete is poured the beams, girders, and columns form a solid concrete framework.

The connections of the beam or girder forms to the column forms are reinforced by the boards *g*. The sides of the beam and girder forms are generally made of 2-inch planks *h*. The function of the triangular pieces *i*, that are nailed in the bottom corners of the beam and girder forms, will be described later. The different depths of the beams and girders can be provided by blocking up the bottom piece *j* to the required distance above the bearing pieces. To keep the beam or girder forms from spreading, wedges *k* are driven between the form boards and the beveled blocks nailed to the ends of the bearing pieces. The pieces *o*, which are set at an angle with the bottom boards on the beam or girder forms and the column forms, are sometimes used to form a bracket at the junction of the beams or girders to the column.

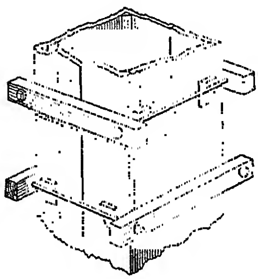


FIG. 52

The forms for the slabs between the beams consist mainly of a platform constructed of $\frac{7}{8}$-inch boards, which are often tongued and grooved. The boards are held together in sections by means of the battens *l*. At the junction of the slab and beams, the boards are supported by the 1-inch strips *m* nailed to the sides of the beam forms. Intermediate supports for the boards are furnished by the $2'' \times 4''$ or $3'' \times 6''$ joists *n* that rest on battens notched out on one side and securely nailed to the sides of the girder forms.

42. Miscellaneous Devices for Forms.—There are many devices that are used for holding forms together. For instance, in the construction of column forms, metal bands are often used for the same purpose as the yokes *f*, Fig. 51. In the column form shown in Fig. 52, bolted yokes are employed.

There are also many devices on the market for supporting the reinforcing bars of slabs, beams, and girders, and for holding them the proper distance apart. Often, the bars are supported on concrete blocks that are cast while the forms are being built.

DETAIL DRAWINGS OF BEAM-AND-GIRDER CONSTRUCTION

CONVENTIONAL METHODS OF REPRESENTATION

43. Introductory Remarks.—Concrete detailing is not nearly so fully developed as steel detailing. Typical methods of representation have not yet become standardized, and the practice in different offices varies considerably. In most engineering offices, no line of division between the design and the detail drawings exists, and all design and detail drawings are prepared by the designer with the assistance of one or more detailers. In some engineering offices and most architectural offices, only general design details are prepared by the reinforced-concrete designers, and the contractor who is to construct the structure is expected to take care of all the other details.

In all concrete detailing, two points should be covered definitely: (1) Ample and exact information should be given to define the outlines of the structure or member so that the forms for its construction can be built without difficulty; (2) sufficient information concerning the details of the reinforcing rods should be supplied to indicate the shape to which the rods should be bent, the points at which bends should be made, and the position the rods should occupy in the structure or member. Usually, the outlines of the concrete and the details of the reinforcing rods are shown and dimensioned on the same drawing, but where the outlines and details are complex, separate drawings are made for the outlines of the concrete and for the details of the reinforcing rods.

44. Methods of Representing Concrete in Section.—The conventional method of representing concrete in section is by means of small triangles and dots, as shown in Figs. 40, 42, 43, and 44. In some railroad offices, parallel dash or full lines are employed for that purpose. The cross-sectioning is generally shown light, and often made with dilute ink, so that the reinforcement in the section shows up distinctly. To save time,

it is customary in many offices of concrete construction co
panies to indicate concrete in section by shading the cro
section with soft pencil. Preferably, the shading should
done on the back of the tracing, so that if changes in
arrangement of the reinforcement or other details in the secti
are made it will not be necessary to go over the shading.

In this Section all concrete in section is represented by mea
of small triangles a
dots.

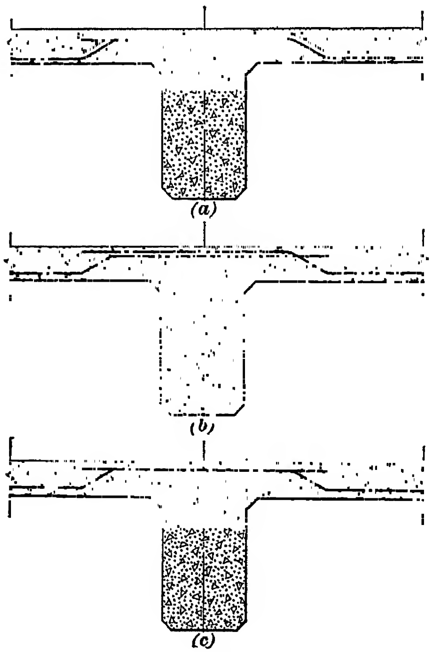


Fig. 53

45. Methods Representing Re forcement.—T
methods of represe
ing reinforcement
by no means unifor
In many large offic
all reinforcement
the plan views, ele
tions, or cross-s
tions of the membe
is represented
means of heavy lin
drawn with lo
dashes and dots, as
Figs. 47, 48, and
In other offices,
reinforcement in t
various views of t
drawings is repr
sented by means of heavy dash lines. In some offices,
main reinforcing rods are represented by heavy full lines, a
stirrups or ties by lighter full lines, while all reinforceme
that projects into the member detailed but belongs to anoth
member is represented by dash lines.

In this Section all reinforcing rods in the various views w
be represented by means of heavy dot-and-dash lines, becau
such lines stand out clearly on the drawing and cannot possib

tively incombustible material, or where the fire hazard is li ited, the steel reinforcement should be covered with not l than $\frac{3}{4}$ inch of concrete in slabs and walls and not less th $1\frac{1}{2}$ inches of concrete in beams, girders, and columns.

Steel reinforcement in wall footings and column footi should have a minimum covering of 3 inches of concrete.

48. Minimum Spacing of Rods.—The reinforcing r in members of concrete structures should be spaced sufficien far apart to allow the concrete to fill the spaces between the Besides, if the rods are placed too close together, the concr between them may fail before the full bond of the reinfor ment can be developed. According to the provisions of t Joint Committee, the clear distance l tween parallel rods should be not l than $1\frac{1}{2}$ times the diameter of round r or $1\frac{1}{2}$ times the diagonal of square ba If the ends of the bars are hooked, t clear spacing may be made equal to t diameter of rounds rods or to the diago of square bars. However, in no c should the clear spacing between rods less than 1 inch, or less than $1\frac{1}{4}$ times the maximum size the coarse aggregate.

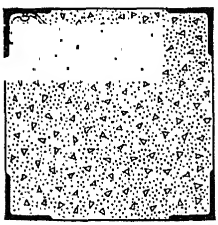


FIG. 54

49. Protection of Corners.—Sharp corners are a source weakness in concrete construction. They often break off wh the forms are removed or chip off easily even after the str ture has been completely finished; difficult patching is th made necessary. Sharp corners should therefore be avoid wherever possible, by chamfering all projecting corners a providing fillets in all entrant corners, as in Fig. 53. Su chamfered corners are called skews. The manner in whi this is accomplished is illustrated in Fig. 51, where triangu pieces *i* are nailed in the bottom corners of the beam and gir forms to provide for chamfering the projecting corners, wh near the top the boards are beveled to provide for concre fillets at the intersections of the slab with the beams girders. The corners of columns should also be chamfered

means of triangular pieces nailed in the forms, as illustrated in Fig. 52. Such chamfering, however, need not be shown on the detail drawings, but may be merely called for by a suitable note.

Where the columns are liable to receive heavy blows, their corners should be protected by means of metal guards. In the column section shown in Fig. 54, the corners are provided with angle-iron guards that are held in place by means of prongs riveted to the angles; one of these prongs is shown in the illustration. Various other types of guards are on the market.

FLOOR PLANS AND SLAB DETAILS

50. Floor Plans.—The floor plans of concrete buildings should show: (1) The location of all columns, beams, and girders; (2) the dimensions and location of all openings; (3) the location of bolts and other inserts; (4) the location and size of reinforcement in the floor slabs; (5) the slope of the floor, if it is sloped for drainage or other purposes.

When the floor plans are drawn to a scale of $\frac{1}{8}$ inch = 1 foot or larger, the beams or girders are drawn to scale and represented by means of two dashed lines, as in Fig. 55, where a part of a floor plan is shown; but when the scale used is $\frac{1}{16}$ inch = 1 foot or less, the beams and girders are represented by means of single heavy full lines, in the same manner as in steel construction. All beams, girders, and columns should be marked with appropriate distinguishing marks, as will be explained later.

In ordinary construction, the floor plans serve also as reinforcing plans for the slabs, as in Fig. 55, where in addition to the location of the various members of the structure, the size and location of the reinforcing rods in the floor slabs are given. In more complex construction, however, separate plans are drawn for the framing of the members and for the reinforcement of the slabs. Foundation bolts are often set in the floors of factory buildings for fastening machines or other equipment; where many such bolts are required they are generally shown on a separate plan.

51. Marks of Members.—According to general practice, the beams of reinforced-concrete structures are usually marked on the plans with the letter *B* and a serial number, such as *B1*, *B2*, *B3*, etc. Similarly, girders are marked with the letter *G* and a serial number, as *G1*, *G2*, *G3*, etc. All beams or girders that have exactly the same details of construction are usually marked with the same mark, as shown in Fig. 55.

Columns are generally marked by a system known as the *coordinate system*. All column lines that are parallel to the top and bottom border lines, or are horizontal on the plan, are lettered and all lines that are parallel to the left and right border lines, or are vertical on the plan, are numbered. The letters and numbers are printed conspicuously in circles placed outside the plan on the lines which they designate. Each column is then referred to by the letter of the horizontal line and the number of the vertical line in which it is located. For instance, in the part plan view in Fig. 55, the columns in the lowest horizontal line are referred to as *A1*, *A2*, *A3*, etc.; in the next horizontal line as *B1*, *B2*, *B3*, etc.; and in the third horizontal line as *C1*, *C2*, *C3*, etc.

52. Details of Slabs.—In indicating the reinforcing rods on the framing plans, or on the reinforcing plans when used in addition to the framing plans, the rods should preferably be shown in diagram as if they were laid down flat, as in Fig. 55. The arrangement of the various bent and straight rods is thus shown to the workmen in a clearer way than would be possible if they were shown in true projection. In many instances, the diagrammatic representation saves drawing cross-sectional views through the slab. The information necessary for bending the rods in the slab is often furnished by a *reinforcement schedule*, which will be explained later. The amount of concrete protection above or below the rods may be specified by a suitable note, such as: *All main slab steel shall be placed* $\frac{3}{4}$ *inch clear above the forms in the bottom of the slab and* $\frac{1}{2}$ *inch clear below the rough surface in the top of the slab.*

53. Marks of Rods.—The rods for slabs, beams, or girders may be bent either at the building site where they are to be

used or at the rolling mills. In either case, great care should be taken to mark each straight or bent rod, or bundle of identical rods, with a clear, indestructible mark stamped on a tag of non-corrodible metal. The tag should be securely fastened to the rod, or bundle of rods, in such manner that it could not be easily detached. Each rod can thus be readily identified and the danger of installing the wrong rods in the slabs, beams, or girders will be greatly reduced.

A simple and efficient method of marking the tags for the various rods, or bundles of rods, is by means of mark numbers, which serve to distinguish each rod, or bundle of rods, from all other rods and also to indicate the size of the rod. In this system of marking, the mark number consists of four figures for rods of $1\frac{1}{4}$-inch diameter and of three figures for rods of smaller diameter. The first figure in mark numbers of three figures, or the first two figures in mark numbers of four figures, indicates the number of eighths of an inch in the diameter of the rod. For example, since the number of eighths in $\frac{1}{4}$ is 2, the first figure in the mark number for a $\frac{1}{4}$-inch-diameter rod is 2. For similar reasons, the first figure in the mark number for a rod of $\frac{3}{8}$-inch diameter is 3, $\frac{1}{2}$-inch diameter 4, $\frac{5}{8}$-inch diameter 5, $\frac{3}{4}$-inch diameter 6, $\frac{7}{8}$-inch diameter 7, 1-inch diameter 8, and $1\frac{1}{8}$-inch diameter 9. For a rod of $1\frac{1}{4}$-inch diameter the first two figures are 10. The remaining figures in the mark number serve to distinguish the rod to which the mark number applies from all other rods of the same size that are of different detail. Thus, rods marked *501* indicate $\frac{5}{8}$-inch square or round rods that differ from the $\frac{5}{8}$-inch rods marked *502*, *503*, *504*, etc. In Fig. 55, the $\frac{1}{2}$-inch diameter rods marked *Mk 401* differ from the $\frac{1}{2}$-inch diameter rods marked *Mk 402*. The symbol *Mk* preceding the mark numbers is here employed to denote *mark*.

In some offices, mark numbers are given only to the bent rods. For instance, the rods *403* in Fig. 55 would be marked $\frac{1}{2}''\phi \times 7'\text{-}0'' \times 12''$ *c. c.* and the mark number omitted, while the rods *404* would be marked as shown in the figure. When the mark number is omitted the length of the rod should be specified.

54. Reinforcement Schedules.—Details of the stra and bent rods used in the slabs, beams, girders, or column conveniently given in a reinforcement schedule, such a illustrated in Fig. 56. Reinforcement schedules are someti shown on the drawings to which they apply, but more o on separate sheets. They are a great help in ordering reinforcement and in bending the rods properly, and t lessen the chances of errors in placing the steel.

In the first column in Fig. 56 is given the mark numbe each type of rod shown on the drawing; in the second colum

REINFORCEMENT SCHEDULE.

Mark No.	Location	No. of Units	No. per Unit	Total No. Required	Size of Rod	Length Ft.	Length In.	BENDING DIAGRAM	Total Leng Feet			
301	Floor Slabs	69	3	207	$\frac{3}{8}''\phi$	22	3	Straight			4	6
302	do.	4	8	32	$\frac{3}{8}''\phi$	8	0	6" 7'-6"				2
401	Floor Slabs	11	19	209	$\frac{1}{2}''\phi$	7	6	Straight			1	5
402	do.	11	20	220	$\frac{1}{2}''\phi$	9	9	8" 1'-1" 4" 6" 3'-10" 6" 3" 3'-2"			2	1
403	do.	58	19	1102	$\frac{1}{2}''\phi$	7	0	Straight			7	7
404	do.	58	20	1160	$\frac{1}{2}''\phi$	10	8	3'-1" 6" 3'-6" 6" 3" 3'-1"		1	2	3
405	Over Girders	54	5	270	$\frac{1}{2}''\phi$	5	0	Straight			1	3
406	do.	24	5	120	$\frac{1}{2}''\phi$	5	0	6" 4'-6"				6

Fig. 56

stated the location of each type of rod to be used; in the th column is given the number of units, or identical parts of structure, in which each type of rod is to be employed; in fourth column is specified the number of rods in each unit, a in the fifth column the total number of rods of each type u in the part of the structure shown on the drawing. The s of the rod is given in the sixth column, and its length, in f and inches, in the next two columns. In the space head *Bending Diagram*, opposite each mark number, is shown detailed diagram of each bent rod, or if the rod is straight, t word *straight* is lettered. The last column is used in estimati

the quantities of steel used, and the total length to the nearest foot of all rods that have the same mark number is inserted there.

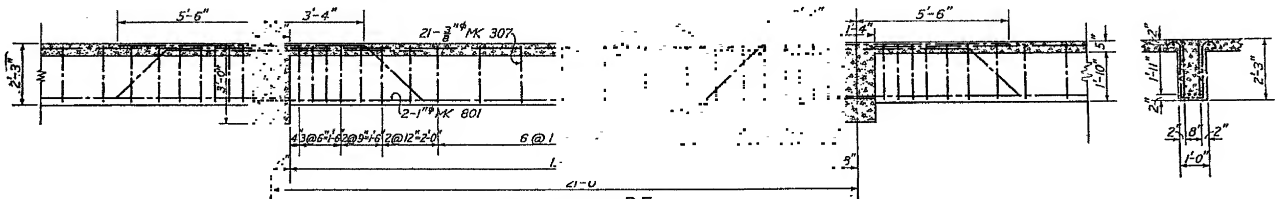
The reinforcement schedule in Fig. 56 applies to the floor, only a part of which is shown in Fig. 55. The $\frac{3}{8}$-inch rods marked *301* are the straight distributing rods in the slabs; they are wired to the $\frac{1}{2}$-inch main rods and run from girder to girder. Each rod is 22 feet 3 inches long, and three such rods are used in each panel between two adjacent beams. The $\frac{3}{8}$-inch rods marked *302*, used in the corners of the floor, are anchored into the lintel beams or girders by means of 6-inch bends shown in the bending diagram.

The $\frac{1}{2}$-inch rods marked *401* are the straight main rods used in the end panels of the floor slab as principal reinforcement. Nineteen such rods are used in the eleven end panels of the floor, and hence the total number of rods is 209. The $\frac{1}{2}$-inch rods marked *402* that are bent as shown in the sketch in the column headed Bending Diagram, are also used as principal reinforcement in the eleven end panels of the floor slab. Twenty rods are used in each panel, or a total of 220. The straight rods marked *403* and the bent rods marked *404* constitute the principal reinforcement of the 58 intermediate panels.

The $\frac{1}{2}$-inch rods marked *405* are straight shear rods placed over the girders. For the wall girders *G3* and *G4*, Fig. 55, the shear rods, marked *406*, are used. These rods are bent down 6 inches at one end to provide for their anchorage into the girders.

DETAILS OF BEAMS AND GIRDERS

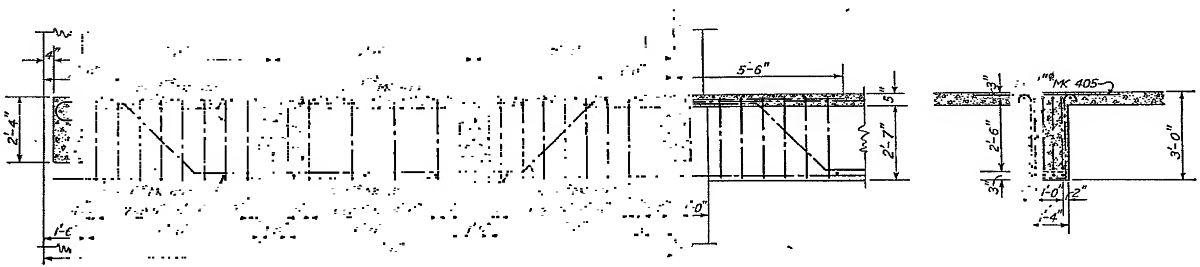
55. Typical Beam and Girder Details.—In detailing reinforced-concrete beams and girders it is customary to show an elevation of the beam or girder and a typical cross-section through it. In complex work, more than one cross-section may sometimes be necessary. A typical detail drawing of a reinforced-concrete beam is shown in Fig. 57, and of a reinforced-concrete girder in Fig. 58. From the point of view of the detailer, there is no material difference between the details of beams and the details of girders; therefore, in all future



Details of Beam B5
(a)

(b)

Fig. 57



Details of Girder G1
(a)

(b)

Fig. 58

discussions the rules applying to the former will apply also to the latter.

The beam drawn in Fig. 57 in elevation in (*a*) and section in (*b*) is the beam *B5* shown in plan view in Fig. 55. It is reinforced with four 1-inch diameter rods, two of which marked *801* are straight and two marked *802* are bent, and twenty-one stirrups marked *307*, made of $\frac{3}{8}$-inch diameter rods, the hooks of the stirrups being wired to two $\frac{3}{8}$-inch diameter rods marked *308*. In order that the various rods in the beam and those projecting from adjacent beams may be distinguished from one another, they are represented diagrammatically and not in true projection. If all the reinforcing rods near the top of the beam were shown at the same level, as they would be shown if a true projection were drawn, it would be difficult to determine where one rod begins and the other ends, while by employing the diagrammatic method of representation all details are brought out clearly. In the cross-sectional view shown in (*b*), the reinforcing rods cut by the section are represented by full circles, the bent portions of these rods are shown in side view by dot-and-dash lines, and the horizontal portions by open circles. As shown in the cross-sectional view, all rods are centered 2 inches above the bottom of the beam and 2 inches below the top of the beam.

In detailing a beam like the one shown in Fig. 57, the following procedure may be conveniently followed: First, the outline of the concrete in the elevation view is drawn, the span of the beam is dimensioned, and above that dimension is given the line of dimensions that locate the surfaces between which the beam frames. The main reinforcing rods in the beam are next indicated and the horizontal portions of the bent rods dimensioned above the elevation view. The stirrups are then shown and their location fixed by a line of dimensions immediately below the elevation view. Finally, the cross-sectional view is drawn and properly dimensioned. The details are finished by placing whatever notes are required to define the construction, marking the various rods in the beam, and recording the sizes of those rods in a reinforcement schedule, such as that shown in Fig. 56, or some other suitable schedule.

The total span of a beam located in the intermediate bays o the floor is the distance between the center lines of the girder or columns into which its frames. For a beam located in th(end bays of the floor, the length which is usually dimensionec is the distance between the outside of the wall girder or wal column into which the beam frames at one end to the cente: line of the intermediate girder or column into which it frame: at the other end.

56. The girder detailed in Fig. 58 is girder *G1* shown ir plan view in Fig. 55. It is reinforced with eight 1-inch diametei rods, placed in two layers, which are separated by means oi short 1-inch diameter rods. All four rods in the lower layei that are marked *803* are straight, while the four rods in the upper layer that are marked *804* are bent. The web reinforcement consists of nineteen stirrups, marked *412*, which are made of $\frac{1}{2}$-inch diameter rods; the hooks of the stirrups are wired tc the two $\frac{1}{2}$-inch diameter rods that are marked *413*. Over the rods in the top of the girder are placed the transverse shear rods of $\frac{1}{2}$-inch diameter that are marked *405*.

In detailing the girder a procedure similar to that described for detailing the beam *B5* in Art. **55** is followed.

57. Spacing of Stirrups.—The spacing of stirrups is determined by the principles of reinforced-concrete design so as to provide ample protection against excessive diagonal tension to which the beam or girder may be subjected as a result of the maximum loading that may come on it. In some offices, stirrups are spaced by arbitrary methods, but such practice is not to be recommended.

According to Joint Committee recommendations, the spacing of vertical stirrups must not exceed one-half of the effective depth of the beam. By the effective depth of the beam is meant the distance from the center of the reinforcement in the bottom of the beam to the top of the beam; in Fig. 57 the effective depth of the beam *B5* is 27 in. − 2 in. = 25 inches, and in Fig. 58 the effective depth of the girder *G1* is 36 in. − 3 in. = 33 inches. Stirrups that are not intended to resist diagonal tension, but which are placed for construc-

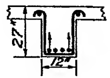
tion purposes to help tie the slab to the stem of the beam, may be spaced farther apart than the minimum specified spacing. Thus, the five stirrups in the middle of the beam *B5* are spaced 18 inches apart, or more than one-half the effective depth of the beam, because in that region the concrete alone is capable of resisting the existing diagonal tension.

The Joint Committee also recommends that the distance from the face of the member into which the beam frames to the first vertical stirrup shall not exceed one-quarter the effective depth of the member. According to this provision, in the beam *B5* the first stirrup could not be placed more than $\frac{25}{4}$ in. $=6\frac{1}{4}$ inches from the face of the girder.

58. Beam and Girder Schedules.—Beam and girder schedules concentrate in convenient tabular form the information concerning the beams and girders that are shown in plan view or are completely detailed on the sheet. There are many types of schedules in common use, the particular type used in an office depending entirely on the system of detailing there employed. For instance, in some offices, no attempt is made to work out complete details of the simpler beams and girders and all information necessary for ordering the steel or for constructing the forms for the members of the structure may be obtained from the beam schedules. In other offices, complete details of all beams and girders are worked out, and beam schedules are added by way of summarizing the information in the details. In still other offices, the beam schedules include bending diagrams for the reinforcing steel, thus obviating the need of reinforcing schedules.

Two representative types of beam schedules are illustrated in Fig. 59. In the schedule shown in (*a*) is given complete information concerning the beam and the reinforcement in it, so that no separate reinforcement schedule is necessary. In the first column is given the distinguishing mark of the beam. The next column, headed *No. Ea. Floor*, is subdivided into as many parts as there are floors in the building; the number of beams used in each floor is recorded in the part headed by the number or the first letter of the name of that floor. Under

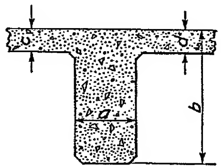
BEAM SCHEDULE

Beam	No. Ea. Floor 1	2	3	R	Reinforcement No.	Size	Length	Mk No.	BENDING DIAGRAM	Beam Section	Stirrups No.	Size	Length	Mk No.	Diagram of Stirrup	Spacing of Stirrups Ea. End	Center
B5	16	30	30	32	2 2 2	1"φ 1"φ $\frac{3}{8}$"φ	22'-0" 33'-7" 20'-0"	801 802 307	8'-10" 2'-8$\frac{1}{2}$" 10'-6" 2'-8$\frac{1}{2}$" 8'-10" Mk 802		21"	$\frac{3}{8}$"φ	5'-6"	307		3@6"c.c. 2@9"c.c. 2@12"c.c.	6@1'-6"c.c.

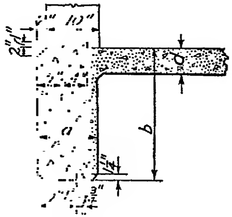
(a)

GIRDER SCHEDULE—THIRD AND FOURTH FLOORS

Mark	Total No.	Size a	b	c	d	Steel Bent	Straight	Stirrups	Top Steel	Shear Rods	Sketch No.
G1	12	1'-4"	3'-0"	5"	5"	4-1"φ	4-1"φ	19-$\frac{1}{2}$"φ	2-$\frac{1}{2}$"φ	15-$\frac{1}{2}$"φ	1
G2	20	1'-4"	3'-0"	5"	5"	4-1"φ	4-1"φ	19-$\frac{1}{2}$"φ	2-$\frac{1}{2}$"φ	15-$\frac{1}{2}$"φ	1
G3	8	1'-0"	2'-4"	0"	5"	4-$\frac{7}{8}$"φ	4-$\frac{7}{8}$"φ	19-$\frac{3}{8}$"φ	2-$\frac{3}{8}$"φ	15-$\frac{1}{2}$"φ	2



SKETCH No. 1



SKETCH No. 2

(b)

Fig. 59

the heading *Reinforcement* are specified the number, size, length, and mark number of the various rods used in the beam. In the space under the heading *Bending Diagram* are shown complete details for the various bent rods used in the beam. A typical cross-section through the beam is shown under the heading *Beam Section;* the bent-up rods in that section are indicated by means of arrows. Under the heading *Stirrups* are given the number, size, length, and mark number of the stirrups in the beam. In the column headed *Diagram of Stirrup* is shown a bending diagram for each stirrup in the beam. The spacing of the stirrups at each end and at the center are given under the heading *Spacing of Stirrups.*

In the girder schedule shown in Fig. 59 (*b*) are specified the total number of girders required in the structure, the dimensions of the cross-section of each girder, and the number and sizes of the various rods and stirrups in the girder. In addition to the schedule, sketches are given of the different cross-sections of the girders covered by the schedule, as *Sketch No. 1* and *Sketch No. 2*. These sketches apply to girders of different sizes, and hence the variable dimensions are indicated by means of letters which are referred to in the schedule under the heading *Size.* The dimensions that are standard for all beams to which the sketch applies are shown on the sketch, as in *Sketch No. 2*. The number of the sketch that applies to any particular girder is given in the last column of the schedule. Thus, according to the schedule, *Sketch No. 1* applies to girders *G1* and *G2*, and *Sketch No. 2* to girder *G3*. The information given in the various columns under the heading *Steel* is of a general nature, and hence to furnish detailed information concerning the bent rods it is necessary to prepare reinforcing schedules on separate sheets. Schedules like that shown in (*b*) also apply to beams, except that the column headed *Shear Rods* is usually omitted because shear rods are seldom used over beams

DETAILS OF COLUMNS

59. Interior Columns.—In detailing a column it is customary to draw an elevation of the entire column, from footing to roof, and one or more cross-sections. A detail drawing of one of the interior columns in the plan shown in Fig. 55 is given in Fig. 60. To conserve space, the column is usually broken between floors. The principal dimensions of the column are the distances between the surfaces of the floor slabs, shown on the elevation, and the outside dimensions of the column, shown on the cross-sections. In some offices, the given distances between the surfaces of the floor slabs are between the rough surfaces of the concrete slabs before the finish is applied, as in Fig. 60, while in others these distances are between finished floor surfaces. The members framing into the column are usually indicated and their over-all dimensions shown or specified. The footing of the column is often detailed on a separate sheet.

The vertical rods and the horizontal ties are indicated by heavy dot-and-dash lines. The location of the vertical rods in the column is generally fixed by dimensions on the cross-sectional views. The length of lap at the splices is specified by dimensions on the elevation. The bends in the rods at splices are clearly indicated but they need not be dimensioned, it being understood that such bends are made at least 1 foot below the rough surface of the concrete slab and at an angle not greater than 30° with the vertical. In the cross-sections, the ties are represented diagrammatically and not in true plan view, in order to indicate how the ends of the ties are bent. Perspective views of ties are shown in Figs. 45 and 46.

In the details shown in Fig. 60, mark numbers are given to the various vertical rods and horizontal ties, as was previously done with the reinforcement of beams and girders. The details of the reinforcement are then shown in the reinforcement schedule. In some offices, it is not customary to use a reinforcement schedule and mark numbers for the reinforcement of columns; the lengths of the various rods are then specified on the drawing.